The Sugar Beet Nematode and Its Control

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Office of Cotton and Truck Disease and Sugar Plant Investigations,
U. S. Department of Agriculture.

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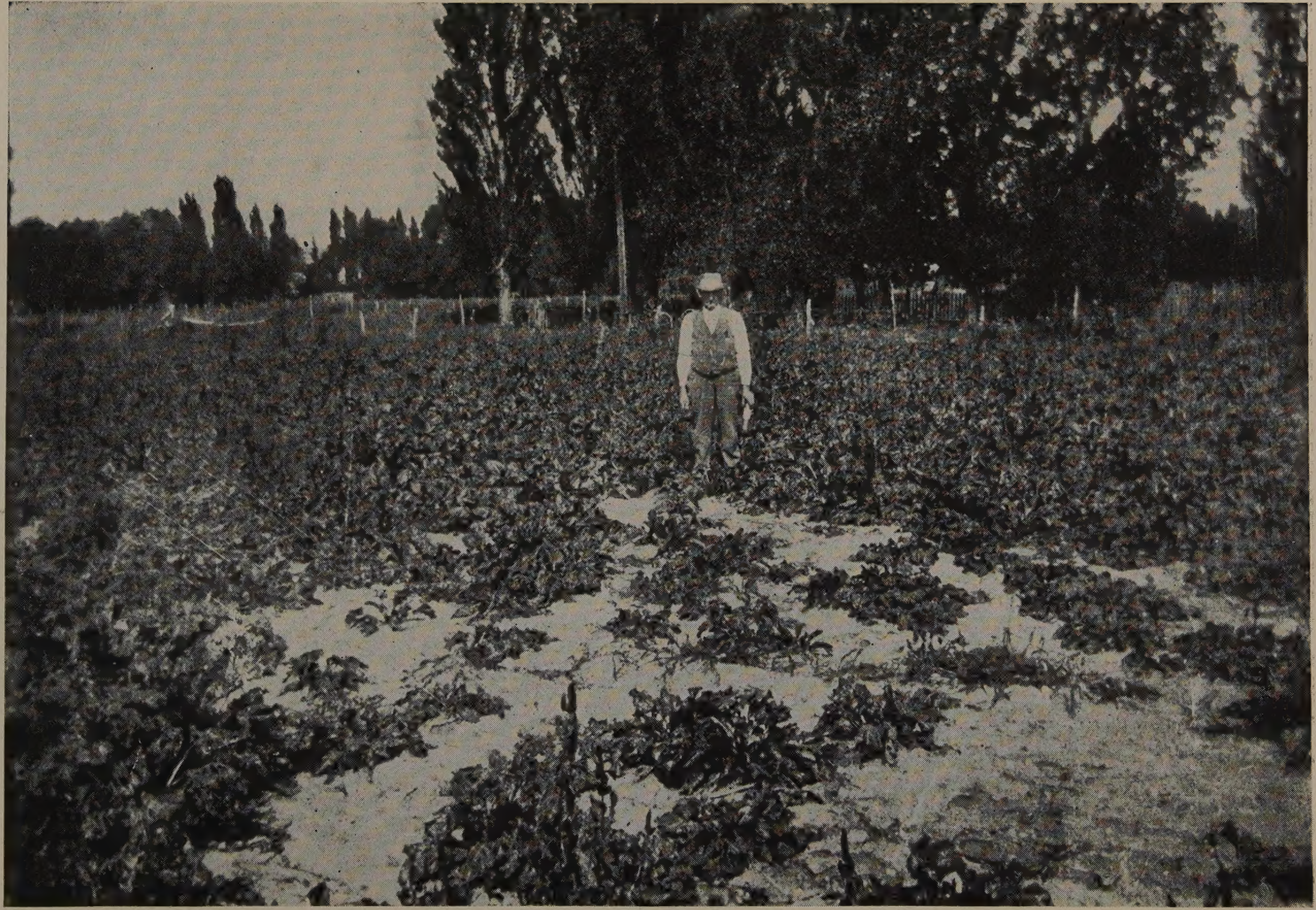

PLATE I.

Field of Sugar Beets near Lehi, Utah, infested with **Heterodera schachtii.** Showing sharply defined infested area.

Photographed by L. P. Byars.

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AUTHOR'S PREFACE.

[Toward the close of 1912 the writer was requested to study the sugar beet nematode, *Heterodera schachtii* Schmidt, in order to ascertain the nature and extent of the injuries caused by it to sugar beets and other crops, as well as the possibility of its introduction and distribution in the United States.

This study resulted in the discovery of a scattered but voluminous European literature covering a period of about sixty years, from which it proved possible to glean most of the data presented in the following pages. No literature could be found on the subject in the English language, therefore it was believed that a digest of the more important contributions to this literature might be of service to students, beet growers and others directly interested in the beet sugar industry.

The bibliography is not quite a complete one, but it cites the more important literature of the subject.

Hearty thanks are extended to Dr. N. A. Cobb and Mr. W. E. Chambers for their valuable assistance in the study of the nematode itself, to Mr. P. L. Ricker for editing and revising the lists of susceptible and non-susceptible plants, and to Miss Florence P. Smith, who verified the bibliography.]

INTRODUCTION.

Attention of late has been called to the fact that many plant diseases have been introduced into this country by means of imported nursery stock, potatoes, and other agricultural products. Legislation recently has been enacted looking to the establishment of a quarantine to prevent, if possible, the continued entrance of such disease or pest-bearing products into the United States.

Among serious pests that already have done much injury in European countries is the sugar-beet nematode, *Heterodera schachtii* Schmidt. The attacks of this microscopic eelworm bring about a physiological disturbance or disease of sugar beets. The sugar beet nematode has become so widely distributed in the beet growing districts of Europe as annually to cause great losses in the sugar beet crop.

Since this pest, unfortunately, already has gained entrance to this country, it is very desirable that information concerning it shall be available, so that steps may at once be taken to prevent its further introduction and distribution. To this end the present paper has been prepared.

The early successes of the beet sugar industry in Europe, under the fostering protection of the respective governments of Germany, of France, of Austria, and later of Russia and the other European countries, amazingly stimulated the cultivation of sugar beets in those countries. Each year saw a large increase in the area devoted to the crop. In response to improved methods and implements, beets continued to yield more generously in both tonnage and sugar.

An assured market and liberal prices at length aroused the avarice of many growers so that finally we find them not only devoting more acreage to beet culture but raising beets many years in succession in the same fields. In consequence of this ill advised procedure, diseases and pests to which the beet is susceptible became generally established and much land was thus unfitted for the further cultivation of sugar beets.

Among other diseases overtaking this valuable crop was one whose present appellation, *Rübenmüdigkeit,* was originally applied to a supposedly exhausted condition of the soil, which was thought to have become deficient in certain necessary mineral plant foods through the repeated cultivation of sugar beets on the same land. The soil then was said to have become "beet tired" or "beet weary."

At first gradually, then with increasing rapidity, this condition became more widespread, until its effects were not less than disastrous. This disease of the sugar beet has now long been associated with the attacks of the sugar beet nematode, or eelworm, *Heterodera schachtii* Schmidt.

The dire consequences of this nematode invasion recently have been graphically depicted by Spiegler (1907), a student of Hollrung and Kühn, who has had an extended practical experience in the beet sugar industry. According to Spiegler, the beet industry was at its heyday in the seventies. Not satisfied with the land already in cultivation, the farmer plowed fertile meadows along the border of river and stream

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wherein to grow sugar beets. At this time, incredible as it may appear, beets were grown on the same land eight to ten years in succession, and not seldom were yields of 20 to 27 tons an acre obtained.

Such bountiful yields stimulated speculation. More and more was meadow and outspreading forest taken over for beet culture. Finally such irrational conduct, through constantly repeated beet growing, rapidly caused an increase of sugar beet pests, especially of the nematode, thus rendering improbable or impossible further beet culture in those places.

Where the nematode had thus become established, sugar beets no longer throve, despite heavy applications of manure and commercial fertilizers.

After the fat years followed lean ones. The gain, squeezed from the land by many years of forced beet culture, was lost. Beet soil, once so productive, again reverted to meadow land.

It might be supposed that the farmer, after such an experience, would prevent further injury, by the adoption of a rational system of crop rotation and the restriction of beet culture. However, such a supposition was not borne out by facts. The earlier ignorance as to the true cause of beet weariness was succeeded by the greatest incredulity when it was made known that a tiny eelworm was the source of the trouble.

About this time various conditions conspired temporarily to make the price of beets very favorable to the growers, so that they began anew to force the cultivation of sugar beets, and in this manner, with equal certainty, to spread the nematodes. In many beet-growing districts, not only the proprietors of sugar factories, but also large and small tenant farmers, and even small landowners, mistreated their fields in this way. As though this were not bad enough, nematodes were propagated and spread by the million in numerous other ways, as by the use of slime from the waste water of the sugar factory, and of compost mixed with nematode-infested soil, applied to the land as fertilizers. The planting of seed beets grown in infested fields carried the parasite to still other fields. Thus, through ignorance, the dangerous pest was introduced under conditions most favorable to it.

As the nematodes constantly gained headway, the yield of beets continued to decrease until finally beets were harvested that, in shape and quality were unfit for the factory. Attempts were made by overmanuring to restore normal yields—a practice in itself extremely injurious to both beets and other crops.

Spiegler had sown grain in such fields, but despite the fact that as much as 71 pounds of seed per acre was sown, accompanied by favorable weather, the grain was completely "lodged," and the yield was unsatisfactory in both quality and quantity. He said:

"The condition of our agriculture ever grows critical; grain and beet prices are low, while labor, fodder, and manure are enormously dear, yet our crops are constantly menaced by this and other pests. In the interest of the whole industry, it then behooves us to unite in fighting the greatest enemy of the sugar beet."

This striking picture should aid the farmer and the beet sugar manufacturer of the United States to realize the nature and extent of the menace offered by the nematode to this promising industry; a menace not merely probable or remote but, unfortunately, already present.

The necessity of an immediate recognition of the fact that this pest has already become established in several of the older beet districts of the United States, that it is locally as disastrous where established in this country as anywhere in Europe, and that hitherto practically no steps have been taken either to check or eradicate it or to prevent its wider distribution is urged.

In order to save the industry in this country from enormous losses and bitter experiences comparable to those endured by European beet growers, no time should be lost in putting into operation preventive measures.

The studies and experiments of the best European agricultural scientists, extending over more than half a century, should guide us to an intelligent and effective method of coping with the problem before it assumes greater proportions.

HISTORY OF THE BEET NEMATODE INVASION IN EUROPE.

Although Achard's experimental factory for the manufacture of beet sugar was opened at Cunern in Silesia in 1799 (Robertson-Scott, [1911]), and the actual cultivation of the sugar beet was begun in 1802 (Briem, [1895]), the growing of beets and extraction of sugar from them was carried on only experimentally in Germany, Austria-Hungary, France and Russia for the next 30 years. In 1812, Achard's factory worked up only about 4,960 pounds of beets daily. Factories handling as many as 6½ tons to 8½ tons of beets per diem were considered large for that time. However, as early as 1836 there were in Germany as many as 21 factories. The industry then began to extend so rapidly that in 1860 there were 184 factories. Ten years later no less than 304 factories were in operation, which handled 3,364,760 short tons of beets. (Eisbein, 1895.)

During this decade of marvelous development, news began to spread that the yield of beets was beginning to fall off. An examination revealed the fact that indeed both yield and quality were suffering. The agricultural chemists of that day came to the conclusion that, through the repeated cropping and intensive culture of sugar beets, the soil had become almost exhausted of certain mineral foods necessary to them. Beets no longer throve in certain tracts of land. The above conclusion was reachced on the ground that beets made a heavy drain on mineral salts in the soil, especially potassium salts. For example, a yield of 20 tons of beets to the acre, with foliage weighing 4.8 tons, takes from the soil 104 pounds of nitrogen, 224 pounds of potassium oxide and 45 pounds of phosphorus pentoxid. It was found that the ash of affected beets contained a smaller percentage of potassium salts than that of healthy ones. Thus it came about that the disease was assumed to be caused by potassium starvation. As a logical result of this conclusion, large sums of money were expended annually for fertilizers containing potassium salts with which to replenish the supposedly exhausted soil. This alleged exhaustion of the soil was named *Rübenmüdigkeit,* or "beet-weariness." (Wimmer [1903] and Liebscher [1878].)

Through the contributions of Julius Kühn (1881, 1882) and the researches of Liebscher (1878) the true cause of this beet malady was at length discovered. By them it was shown indubitably that an eelworm, or nematode, already discovered as early as 1859 by Schacht (1859), was the real culprit. However, the name applied to the infested soil was retained and still is commonly applied to the symptoms shown by beets suffering from the attacks of this eelworm.

A thorough study of the anatomy and morphology of the beet nematode was carried out by Adolf Schmidt (1871), and later by Strubell (1888), Chatin (1888, 1891), and others.

The gravity of the situation may be appreciated on learning that in 1876, according to Rimpau, no less than 24 beet-sugar factories were closed on account of the ravages of the beet nematode.

In 1889, an experiment station was founded, with an annual appropriation of 7,000 marks, to study methods for the destruction of this pest, under the able direction of Hollrung. (Wimmer, 1903.)

Scarcely had the ill effects of the nematode been demonstrated in Germany, when Prillieux, in 1879, made known its wide distribution in France; E. Warming (1879) in Finland; Chatin in Holland; and Liebenberg, Strohmer and Vañha in Austria. Through the investigations of Aimé Girard (1884) the alarming extent of the devastations in the beet districts of France was revealed. This pest had then already become widely spread in Bohemia, but no one was able to specify the time or manner of its introduction. The first account of the matter appeared in the *Chrudimer Landwirtschaftliche Zeitung* of July 31, 1886, in a paper by Lad. Jozek. In 1890, Vejdovsky contributed another paper in the *Zeitung für Zuckerindustrie in Boehmen.* (Hollrung, 1890).

As already stated, the beet nematode was first discovered and described by Schacht (1859). Schmidt (1871, 1872) investigated the pest in 1870, and named it *Heterodera schachtii.* During the years 1866, 1870, 1871, and 1877, it received the attention of Leuckart, Ph. Greeff, Redekewic, Örley, G. Dureau, and others. Kühn (1881, 1882) was the first to demonstrate that the injuries shown by the beets were due to the attacks of the beet nematode.

The most notable data on the anatomy and physiology of the beet nematode were contributed by A. Strubell (1888), while the earliest zoological researches were conducted by J. Chatin (1891). Vañha and Stoklasa in 1896, described minutely its phytopathological significance. Neměc, in 1910 and 1911, studied and described the histological changes and disturbances induced by the attacks of the sugar beet nematode in the tissues of beet rootlets. Very recently Fuchs (1911) has made important additions to our knowledge of the brown cyst or preservation form of this nematode.

In 1907, Spiegler (1907), who studied under Kühn and Hollrung, very graphically summarized the history of the nematode invasion in Germany. The student is referred to Stift's *Zur Geschichte der Rübennematoden,*" for a complete historical review of this subject, chronologically arranged.

The sugar-beet nematode is a great enemy, and has been a formidable menace to the beet-sugar industry of Europe, but at the present time, through a better understanding of its nature, it is becoming less feared. The discussion of the subject is still taken up with frequency and at length in the literature of Europe in a manner indicating clearly that the problem is a grave one.

It is not definitely known when this pest was introduced into the United States, but, judging from the degree to which it had become established in the oldest beet districts of California and Utah, when observed by Bessey in 1907, it must have gained admission quite a number of years prior to his survey. In these localities its ~~become established in the oldest beet dis-~~ spread was at first rather slow, probably on account of the stiff soils prevalent there.

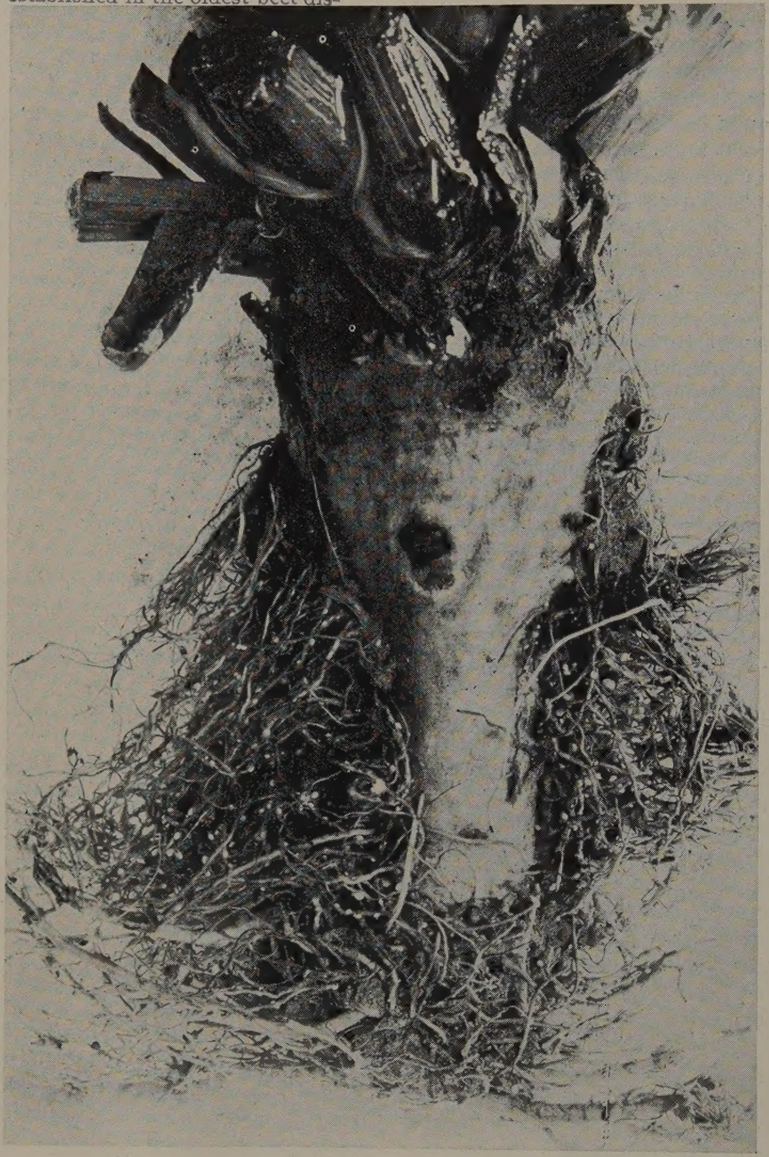

PLATE II.
Typical condition of sugar beets when rootlets are infested with beet nematodes. (Twice natural size.) Photographed by the author.

A recent survey (1912) shows that this nematode is steadily spreading in the above-mentioned localities, but that apparently there are still many districts into which it has not been introduced.

SYMPTOMS PRODUCED IN THE BEET THROUGH NEMATODE ATTACKS.

The effects of nematode attack frequently appear in restricted areas and sharply defined spots in beet fields, but may extend over entire fields. (Pl. I.) Toward the end of July, or early in August, spots may be noted where the beet foliage has assumed a lighter tint than is normal, and the leaves droop until they lie prone upon the ground. The outer leaves become yellowish, spotted and generally discolored, then wilt and die. The inner leaves fail to attain normal size, and when the plant is severely attacked they also die. Then the crown may become blackened with a rot which might penetrate the root and finally cause the flesh of the beet to become brown and limp. This rot is to be attributed to a bacterial or fungous invasion due to the weakened condition of the beet and is not directly caused by the nematodes. Should the attack be not very severe, the beet may sur-

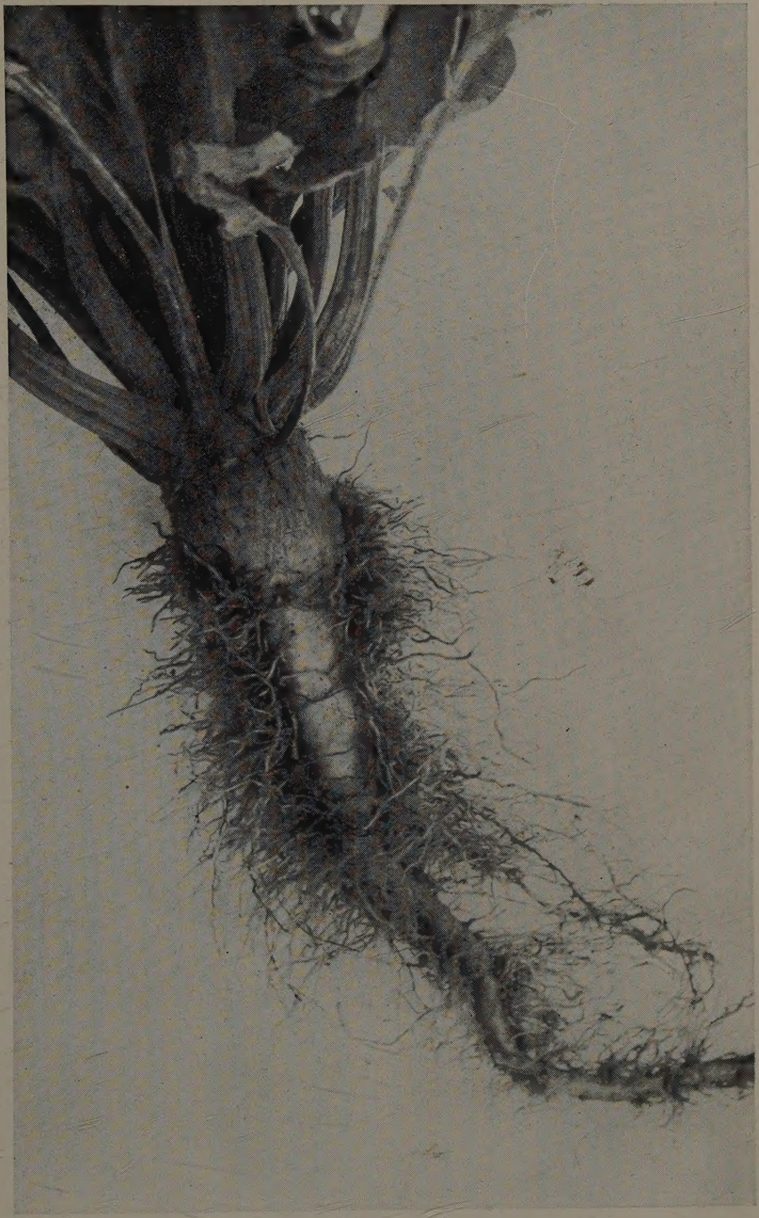

PLATE III.

A sugar beet affected with curly-top. Showing the characteristic dense mass of lateral rootlets, known as "whiskered beet."

Photographed by the author.

vive until harvest, in which case new heart leaves are developed; these, however, do not attain normal size, are often curled and distorted, and assume a dark-green color. The cause of this partial recovery, with the growth of new heart leaves, has not been fully determined, but it has been ascertained that practically no nematodes are to be found on badly wilted beets. It is probable that in many cases the worms leave badly affected beets to seek fresh plants. Plants thus deserted by the pest

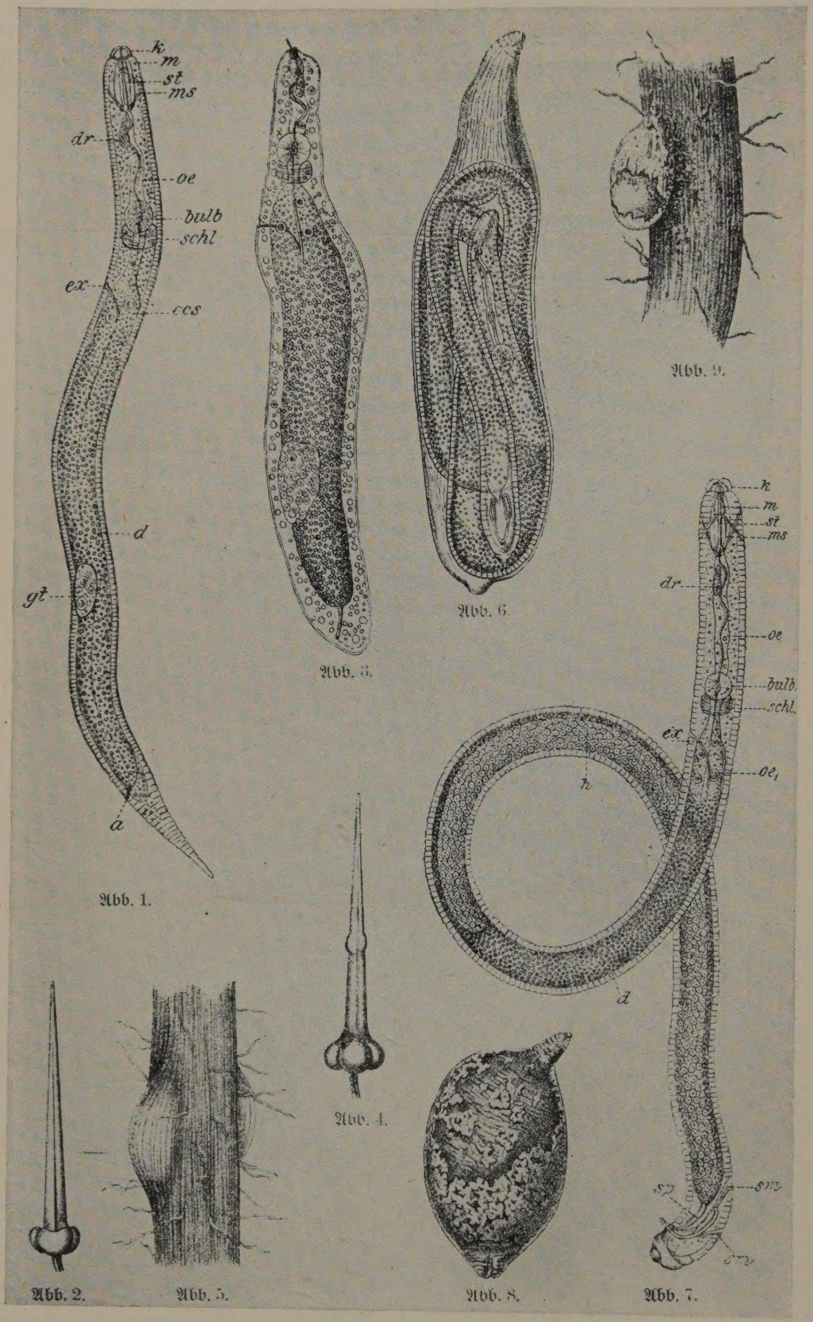

PLATE IV.
Structure of Heterodera schachtii.—(After Strubell.)
(For detailed explanation see page 55.)

are able, in many instances, to make a sufficient degree of recovery to put out new leaves. Since all the older leaves have died these dark green heart leaves are very conspicuous and characteristic. In very badly infested fields, the first symptoms may appear as early as the beginning of June, and under unfavorable conditions the beets may die before the end of that month. Affected beets form an abnormally large number of lateral rootlets. This occurs through the successive death of new growths of rootlets, each set taking up the functions of the dead ones of the preceding growth. Finally, a striking appearance is presented by the dense mass of rootlets, a phenomenon that has earned the names "hunger roots," "bearded roots," "hairy-root," etc. (Pl. II.) This phenomenon appears to be almost identical with that produced in severe cases of the curly-top disease of beets, (Shaw, 1910),

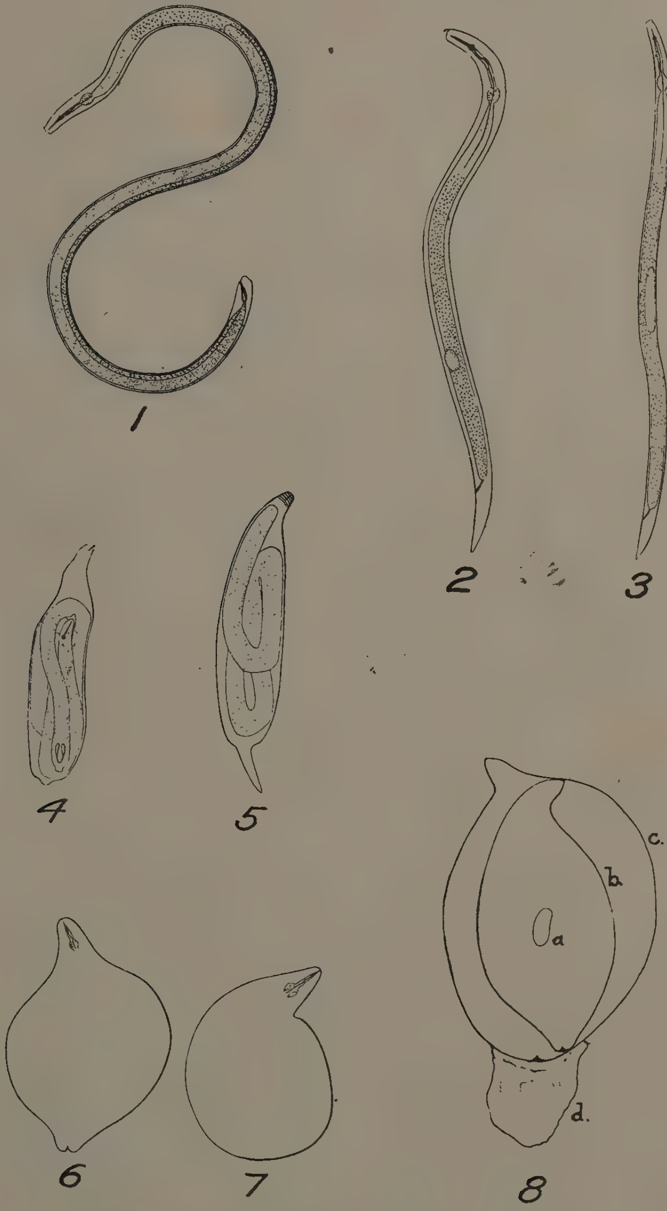

PLATE V.
Comparison of Heterodera schachtii and H. radicicola.
(For detailed explanation see page 55.).

and locally known in this country as "whiskered beets." (Pl. III.)

Numerous milk-white beads, 0.8 to 1.3 millimeter in diameter may be observed on the fine rootlets. These are the protruding bodies of adult female nematodes. (Pls. II, and IV, fig. 9.) Occasionally small swellings may be seen on the rootlets. (Pl. IV, fig. 5.) These occur chiefly where larvæ have been at work for a short time. When many of these occur close together, the resemblance to the swellings and galls caused by the root-knot nematode, *Heterodera radicicola,* may be quite marked, but later the swellings are absorbed or buried in the continued growth of the roots. (Marcinowski, 1909). According to Hollrung (1891) nematodes are no longer to be found on the roots during the last stages of the disease. This is corroborated by Liebscher, who states that no nematodes are to be found on dead or dying beets in badly infested fields. On the other hand, they were found on beets that had made some recovery, or shown resistance, and had produced the above described dark green foliage. Sorauer (1906) states that in Europe the disease has two periods of great severity, namely, the beginning of June and of August.

THE CAUSAL PARASITE.

The sugar-beet nematode, *Heterodera schachtii,* Schmidt, (*H. göttingiana,* Liebscher), has received the attention of many European investigators for more than half a century. Additions made from time to time render the knowledge of it fairly complete. The following is a summary of a more detailed description by Strubell (1888):

Male Nematode.—The male nematode is cylindrical, distinctly banded, from 0.8 to 1 millimeter long (Pl. IV, fig. 7; Pl. V, fig. 1). At the anterior extremity is a 6-rayed, cuticularized, cup-shaped, circular protuberance, formed by an annular depression called "the lips." The posterior end is spindle shaped, somewhat flattened, terminating in a slightly constricted and rounded end, the extreme tip being hooked and bent toward the ventral side. The intestine and single testis are straight. The spear is large (Pl. IV, fig. 4), as are also the two equal-sized spicules.

Female Nematode.—The female nematode (Pl. IV, figs. 8 and 9; Pl. V, fig. 6) is from 0.8 to 1.3 millimeter in length, yellowish white in color and broadly oval, with a narrow necklike anterior portion, the posterior part becoming spindle shaped and containing the vulva. The anal opening is dorsal. The cuticle is thickened and without rings, but is armed with transverse, irregular rugæ. Often the body is covered with thin, translucent, tattered remnants of the larval skin. The anterior end is without lips, though generally covered with yellow to red globules derived from the sap of the sugar beet. The spear is smaller than that of the male. From the vulva there is sometimes suspended a gelatinous body, as large as the worm itself, namely the egg sac, containing the eggs, and formed of a hardened secretion exuded from the inner sexual organs.

BIOLOGY OF THE PARASITE.

Within the body of the dead adult female (Pl. IV, fig. 8) may be seen as many as 350 bean or kidney-shaped eggs (Pl. V, fig. 8*a*), having an average length of 0.08 millimeter and a width of 0.04 millimeter, together with some larval worms. Under the influence of the temperature and moisture of July and August, the body of the dead adult female becomes so swollen that the vulva is mechanically opened and the larvæ are able to escape. During dry summers this may be postponed until September, or even later. The wormlike larvæ (Pl. IV, fig. 1; Pl. V, fig. 2) are about 0.36 millimeter in length and 0.016 millimeter in thickness and are provided with lips like those seen in the adult male, but the posterior end has an elongated though somewhat rounded and barrel-shaped termination. The comparatively large spear (Pl. IV, fig. 2) has at its basal end three spherical swellings that are hooked or bent upon the upper side. The sexual organs are in an embryonic condition. On the host plant, the larvæ seek lateral rootlets having an average diameter of 1 millimeter and bore into their peripheral portions, leaving the central vascular-bundle area untouched. The first molting takes place shortly after the larvæ enter the root. The lips around the mouth parts are replaced by a small, ring-shaped mouth opening composed of chitin. The larval spear is replaced by a smaller one, destitute of the curved terminations to the three basal swellings. Following the molting, the body of the worm assumes a sac shape, having the general form of a flask or club, with a prolonged anterior portion, and a subcylindrical posterior portion, in the middle of which is located the anal opening (Pl. IV, fig. 3). At the same time the tissues of the root, inclosing the worm, become swollen (Pl. IV, fig. 5).

From this point the development of the female becomes entirely different from that of the male. It gradually assumes a more globular form, the anterior portion being in strong contrast to the posterior. The double ovaries rapidly develop, and the intestine becomes greatly enlarged. The vulva changes its position from the ventral side to the posterior end, becomes swollen in form and protrudes from the body. (Pl. IV, fig. 8; Pl. V, fig. 6.) The anal opening is now located upon the dorsal side of the worm. The outer layers of the root become ruptured by the growing female, the posterior end of which protrudes, so as to afford opportunity for fertilization by the male (Pl. IV, fig. 9). The muscles and the intestine become more and more compressed by the rapidly growing ovaries. The entire body of the now greatly enlarged female is at this period outside of the root, except its mouth parts, which are firmly fixed within the tissues. By the time the eggs are fully mature the female dies and becomes disconnected from the root. Its skin is brown, of a tough texture, and incloses not only the eggs, but larvæ developed from them.[1]

In the case of the male, the early, larval, flask shape (Pl. IV, fig. 6) is soon lost, and during the succeeding metamorphosis the small anterior spear is replaced by a more robust one (Pl. IV, fig. 4). The adult male breaks through its larval skin, as well as through the tissues of the root, and escapes into the soil, through which it travels in search of the female. After conjugation it soon dies. The development of the female occupies four to five weeks, so that in a single season as many as six or seven generations of this nematode may be produced. Strubell states that in the case of thin rootlets it frequently happens that only the head of the nematode is introduced, the rest of the body remaining without.

DIMENSIONS OF THE BEET NEMATODE.

Marcinowski (1909) confirms Strubell's (1888) description as a whole, but makes the following corrections in the measurements of the former:

Strubell states that the length of the male is 0.08 to 0.09 millimeter, with 1 millimeter as the longest, while Marcinowski found some males 1.37 millimeters long.

COMPARISON WITH HETERODERA RADICICOLA.

In order to facilitate the determination of the two species shown in Table II, Bessey (1911) points out certain differences between the beet nematode and the root-knot nematode, *Heterodera radicicola.*

The measurement formulæ, as given below, according to the system of Cobb (1902) are based (1) on the actual measurement of the drawings of Strubell, and (2) on the average size of the worms.

Formula 1 of each pair represents the actual measurements of the drawings referred to. Formula 2 is based on the average size of the nematode itself. The numbers above and below the line represent percentages of the total length of the worm.

The Cobb system is as follows: The numbers above a given horizontal line represent the longitudinal measurements, while those below the line indicate the diameter of the worm at those points. The number at the end of the line represents the total length of the worm or drawing.

For example: In figure 1 the first number above the outline (1.5) indicates the length of the lips, and the first number below the outline (3) indicates the diameter of that portion of the head part. The second number above the line (8.7) represents the distance from the anterior extremity of the animal to the bottom of the pharynx or buccal cavity; the second number below the outline (6) represents the length of the body diameter which passes through the base of the pharynx. The third number above the outline (26) gives the distance from the anterior extremity to the center of the nerve ring, and the number directly below (6.5) represents the corresponding body diameter. The fourth pair of numbers (31 and 6.5) are the measurements relating to the posterior end of the œsophagus, or base of the neck. The fifth number above the outline corresponds to V., in Formula 1, for the first larval stage and indicates the position of the vulva, while the number below (6.2) shows the diameter at that part. The last pair of numbers (100 and 4.7) are the distances from the anterior extremity to the anus and the diameter at that point.

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[1] The studies of Chatin, and later, of Fuchs, show that not all adult females assume this brown stage, which is a condition quite different from that of the mature, living female. Those females which do not reach the "brown cyst" stage fall off the rootlets on the approach of cool weather and perish, together with the eggs and larvae they may contain. Such larvae as may have been able to hatch out during mild weather in the late autumn, also die when cold weather supervenes. Comparatively few of the females of the generations produced during the early part of a season, and throughout the summer, reach this brown, tough condition; instead, while still of a whitish tint, and when their eggs are mature, they die and fall from the rootlets. Thereupon the eggs begin to hatch and the larvae to emerge and seek suitable host plants. Even during the summer, however, a small percentage of the adult females undergo this change, so well described by Chatin and Fuchs. (See chapter on the brown cyst.) As the autumn advances, accompanied by cool weather, the proportion of females assuming the brown-cyst form becomes progressively greater. The brown cysts fall from the rootlets into the ground, and there protect the eggs which they contain against the vicissitudes of the winter; and, should later conditions be unfavorable to their further development, the eggs may still be preserved in the ground for years by the tough integument of the cysts.

THE BROWN-CYST OR PRESERVATION STAGE.

The more elaborate studies of Chatin (1887) especially on certain modifications undergone by the pregnant females under some conditions, are of great importance.

First larval stage:

$$\text{Formula 1,}\ \frac{1.5\quad 8.7\quad 26\quad 31\quad V\,75\quad 100}{3\quad 6\quad 6.5\quad 6.5\quad 6.2\quad 4.7}$$

115 mm. = Actual measurements of drawing (Pl. V., fig. 1).

$$\text{Formula 2,}\ \frac{1\quad 7.6\quad 23\quad 27\quad V.\quad 87}{2.6\quad 5.2\quad 5.6\quad 5.6\quad 5.4\quad 4.1}$$

0.35 mm. = Average length of larva (formula in percentages).

Male:

$$\text{Formula 1,}\ \frac{1.5\quad 10\quad 31\quad 35\quad -M\,112\quad 197}{3.5\quad 6\quad 6.5\quad 6.5\quad 6\quad 6}$$

200 mm. = Actual measurements of drawing (Pl. V., fig. 7).

$$\text{Formula 2,}\ \frac{0.8\quad 5\quad 16\quad 18\quad -M\,56\quad 98}{1.8\quad 3\quad 3.3\quad 3.3\quad 3\quad 3}$$

1 mm. = Average length of male (formula in percentages).

V = the vulva. -M. = one straight testicle extending forward.

The following is a translation of Chatin's two papers on the "brown-cyst" form:

Among nematodes parasitic on vegetables there is one which has in recent years gained especial notoriety. This is *Heterodera schachtii*, which lives on the roots of several plants, but chiefly on the sugar beet. The larvæ, small and tenuous, penetrate the rootlets, then become transformed into the adult stage, in which they present considerable sexual differences. The males alone retain the classic and filiform shape of nematodes, while the females, swollen by the development of the eggs, very soon present the form of small, ovoid, whitish masses, their cephalic extremity being embedded in the cortex of the roots. These facts are well known today, but several points appear to have escaped the authors (Kühn, Strubell, etc.) who have attempted to learn the history of this remarkable worm. Several variations in the thickness and color of the integument of the female have been noted. A vague allusion to this has been made by Strubell.

During the warm season, the pregnant females are very quickly disintegrated by the rapid enlargement which their bodies undergo, and by the liberation of the eggs and larvæ contained in the body sac, but under certain circumstances, and especially on the approach of winter, it has been established that important changes take place in some of these females—changes that are of special interest.

The epidermis, at first very thin, progressively thickens. Its glands furnish an abundant secretion that forms an agglutinated mass of organic and mineral substances, thus surrounding the females with a kind of cyst or sac of mixed character. During development, this cyst ends by covering the buccal and vulvular openings. The spear, which the parasite has fixed in the vegetable tissues, can not, as formerly, perform its functions. All connection is then broken between the worm and host plant.

One no longer sees an animal, but a cyst filled with eggs, which now falls into the mixture of rootlets and soil. The shape of the cyst is variable—ovoid, navicular or biconical. It measures, on the average, 0.6 millimeter in its longest diameter. It is of a brownish color, and is protected by very thick and scarcely permeable walls. It is now apparent in what respect it differs from the ordinary pregnant female. The latter has a white tint and a very thin and variable epidermis that is broken by the slightest shock, or under the least osmotic pressure.

It is easy to explain how a cyst thus constituted may survive the winter season and afford a strong protection to the inclosed eggs. More slowly, under the influence of conditions favorable to its dehiscence, the walls become distended, soften, and finally allow the eggs and larvæ to escape. The eggs hatch, and the larvæ, reaching the adjacent rootlets, attain their complete development; the females become impregnated, and the parasite is rapidly multiplied. The phenomena accompanying the bursting of the cyst and the liberation of eggs and larvæ require for their accomplishment a period varying with the temperature, humidity, etc. I carried out the following experiment: At the end of May, the average temperature of the room being 12° C., I placed some brown cysts in a glass dish with a small quantity of moist soil. At the end of nine days young worms appeared in fairly large number.

It scarcely need be added that the soil used in this experiment came from a spot that had never been cultivated with any plant infested by nematodes, and which I am sure from repeated observations had never contained *H. schachtii* before the cysts were placed in it.

The formation of the brown cysts, then, brings about a condition especially favorable to the propagation of the species and enables one to understand the failure of most of the methods that have been attempted for the destruction of the nematode.

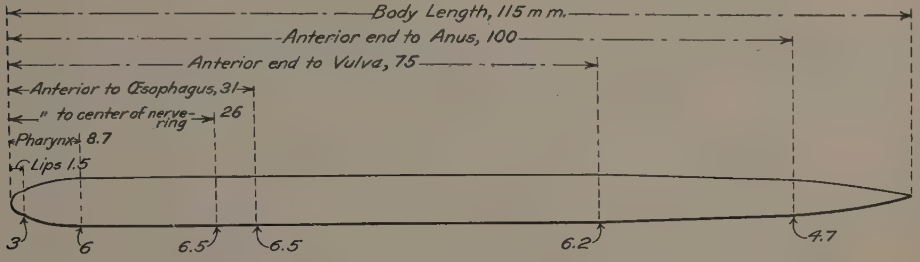
Body Length, 115 m m.
Anterior end to Anus, 100
Anterior end to Vulva, 75
Anterior to Œsophagus, 31
" to center of nerve-ring 26
Pharynx 8.7
Lips 1.5
3
6
6.5
6.5
6.2
4.7

FIG. 1.

An understanding of these cysts is equally important in researches on the parasite. In spring, when one examines beets taken from silos, there can not be seen any white body on the rootlets, or any trace of nematodes on the surface of the beet. Thus, one might conclude that nematodes are absent, but before reaching such a conclusion it would be necessary carefully to wash the mixture of soil and rootlets and examine it under a lens. Quite frequently there would be discovered, mixed with the grains of sand, from which it would be difficult to distinguish them, these small, brown cysts, which, as we have seen, present a double interest for both the biology and prophylaxis of the worm.

HISTOLOGY OF THE BROWN CYST.

In a later paper, Chatin describes the histology of the brown cyst, as follows:

I. In making known the method of formation of the brown cysts that protect the eggs of *Heterodera schachtii* during the winter, and powerfully contribute toward an assurance of the propagation of the parasite, I have to refer to modifications taking place in the integument of the pregnant female, and would add that this observation was a particularly delicate one. The microscopic dimensions of the worm, the tenuity and slight differentiation of certain tissues, the rapidity with which the phenomena that accomplish this succeed each other, etc., create numerous difficulties and enforce considerable reserve in an interpretation of the results obtained.

II. When the integument of a young, adult female is examined by means of colored reagents, it may be observed to consist of an epiderm and an endoderm covering the somatic musculature. The epiderm presents two distinct layers: (1) Superficial or striated, and (2) deep or fibrous. The superficial layer is transparent, refractive, and, for the most part,

TABLE I.—*Measurements of the sugar-beet nematode.*

Sex or Stage.	Dimension relations.	Author.	
		Strubell.	Marcinowski.
Male	$\frac{\text{Length}}{\text{Thickness}}$	32	32
Larva	$\frac{\text{Length}}{\text{Thickness}}$	17	21
Male	$\frac{\text{Body length}}{\text{Spear length}}$	21.5	46
Female	$\frac{\text{Body length}}{\text{Spear length}}$	11	33
Larva	$\frac{\text{Body length}}{\text{Spear length}}$	13	(minimum) 15

TABLE II.—*Comparison of the sugar-beet and root-knot nematodes.*

Points.	H. schachtii.	H. radicicola.
Effect on host.	No galls (Pl. II)	Produces galls on roots (Pl. VI).
Location of mature female.	External; anterior end only within tissues of root (Pl. IV, fig. 9).	Usually entirely within tissues of root; more rarely the posterior portion, very rarely nearly the whole body external.
Shape of female, external appearance.	Mostly lemon shaped, dull and flaky in appearance; no trace of transverse rings (Pl. IV, fig. 8; Pl. V, fig. 6).	Pear or flask shaped, glistening, and pearly white; transverse rings of cuticle often visible on anterior portion (Pl. V, fig. 7).
Eggs.	Part deposited outside body, but most developing within.	All but the last few deposited outside the body.
Larva	Buccal spear about 25 μ (Pl. IV, fig. 2).	Buccal spear about 10 to 15 μ.
Mature male.	Buccal spear about 30 μ (Strubell, 1888; Pl. IV, fig. 4).	Buccal spear mostly about 24 μ.

resistant to chemical agents, especially alkalies; it possesses graceful, circular striæ, due to the presence of annular segments, separated by fine grooves; the deep layer, very difficult to distinguish, is generally thin, and appears to be formed of intersecting fibers.

The endoderm is here represented by a granular layer, in which some nuclei may be seen very clearly, but they are not abundant. A real cellular structure can not be discovered, even with an immersion lens or by varying the technic.

Immediately below that layer appear muscles in longitudinal bundles, running obliquely and less symmetrically than in the male. During this period the thickness of the muscular layer is always very noteworthy.

III. The first change observed in the tissues after fecundation is to be seen as a diminution in the number of nuclei in the endoderm; simultaneously, the whole of that zone becomes more transparent. The epiderm and musculature remain normal.

IV. Soon the female rapidly enlarges, and a progressive diminution in the thickness of the musculature is to be seen. This consists of a kind of delamination. The result of this modification is easily appreciated. It causes a marked attenuation of the entire dermo-muscular tube.

V. In the following stage the tendency just described appears to be arrested, and one is tempted to accord to the musculocutaneous envelope an importance equal to that possessed by it at the beginning of the observations, but a careful analysis always shows considerable differences; the muscular layer, as first developed, becomes thinner and thinner, but this is masked by the changes that take place in the endoderm.

It has been seen (III) that the endoderm shows but a few scattered nuclei. The number of these now augments in a remarkable manner. Their division brings about a certain symmetry, and the spaces which separate them become more nearly equal. The structure of the endoderm will never approach more closely that of the cellular lamina. However, I hesitate to employ a term that expresses an approach, rather than a real assimilation, the cellular field being always very indistinctly indicated. Another fact serves to show that the endoderm at this time acquires a special value. Simultaneously with the proliferation just mentioned is the appearance of viscous and refractive globules collecting on the surface of the epidermis. This secretion, or exudation, is not found to take place from the pores of the epidermis, of which no trace is discovered, but from local ruptures in it, as it gives way under the enormous growth of the body when distended with eggs.

VI. The muscular layers having now disappeared, scarcely a last vestige of them can be discovered in a thin bandlet applied to the endoderm, which itself is greatly attenuated and may be mistaken for the epiderm. The ultimate fate of this varies according to conditions. If the eggs are immediately to be set free, the epiderm is ruptured at several points, and, after having resisted longer than the other tissues, at length, in turn, disintegrates. If, on the contrary, the eggs are to remain in the brown cyst, the latter is formed by means of the above-mentioned exudation, which agglutinates the surrounding particles and unites the fragments of the integument into the protective shell already described.

VII. The facts recited are interesting from several points of view: (1) Concerning the histology of the nematodes, they show that the integument and the musculature, may manifest, at the same stage of evolution, different, even inverse, modifications, which should now be clearly distinguished, in spite of assertions to the contrary by several authors; (2) in their processes and effects certain transformations in the integument resemble some histological phenomena observed in other invertebrates; (3) the brown cyst is of mixed adventitious origin, and can neither be ascribed to a pathological neoplasm appearing in the tissues of the host, nor to an induration of the integument of the worm; (4) the prophylaxis, subordinated to an acquired knowledge of the biology of the parasite, may equally be inspired by the preceding conceptions, for it is likely that we should try above all to get at the mothers at the stage when their integuments, disorganized by the complex histological modifications, can no longer assure them a sufficient protection.

STRUCTURE AND SIGNIFICANCE OF THE BROWN CYST.

The more recent researches of Fuchs (1911) on the brown-cyst stage of the female of *Heterodera schachtii* have revealed facts of such importance to a proper understanding of the life history of this eelworm (facts which may also suggest a proper course of action for effectively combating the pest) that, as with the memoirs of Chatin, no apology is offered for presenting his contribution almost entire.

He stated that the cyst is preeminently the preservation form of the worm, a form making it possible for *Heterodera schachtii* to overwinter without plant food; and in the warm season, in the absence of proper host plants, to retain the contents in a viable condition until suitable food plants may again be present.

It would be an error to conclude that a brown cyst arises from every female, or that the cyst is simply a dead, mature female—a view held by all the earlier investigators, with the exception of Chatin. On the contrary, special changes must take place, precursors of the cyst form. All females that do not undergo these changes fall from the rootlets at their death and perish during the same year. In the latter case, the eggs and larvæ are liberated, if the season permit, and are then able to infest new plants. However, should autumn have arrived with its cool weather and conditions unfavorable to the young brood, these eggs and larvæ perish, since they are not in a state to overwinter in a free condition in the soil.

He convinced himself of this in the following manner: A large number of the brown cysts were carefully opened with a scalpel, allowing the tiny larvæ and multitude of eggs to float in a 0.75 percent solution of sodium chloride, being careful in the operation to avoid injuring the eggs. The above solution was chosen after the example of Strubell, who has observed that the eggs develop in a perfectly normal manner in that solution; while equally in pure water and in stronger solutions they perish more or less rapidly. Then this solution, abundantly laden with eggs and larvæ, was filtered through glass wool, through which the eggs and larvæ could easily pass, the cysts being held back. This solution was allowed to run into vessels of sterile soil, which were then (November, 1909) set out in the garden, remaining there during the winter of 1909-10. In April, 1910, some *Sinapis alba* was sown in these pots, and after three weeks and again four weeks later, they were examined. Not a single worm could be found on these occasions, although plants in a control pot containing soil infested with cysts, and in which white mustard had been sown, when examined at the same time were found to be abundantly infested with larvæ, although the soil of this pot had been exposed to the same degree of cold.

Should the female, however, be changing into the preservation form, modifications which come about shortly before the death of the creature may be observed. Through the sudden enlargement of the genital apparatus, great egg production and an entire absence of any movement whatever, the muscles are reduced to small, often scarcely perceptible bands, which adhere closely to the epidermis. These are covered by a strongly developed cuticle, upon which the larval cast lies in patches.

Should the female now be so far developed as to have reached the lemon stage, on account of copious egg production, conspicuous changes may be seen to take place in the epidermis. Simultaneously, the nuclei multiply and the surrounding protoplasm becomes more opaque, and very refractive droplets are formed within it; the latter then being exuded through the epidermis. Chatin, who had already observed this, was of the opinion that these droplets came to the surface only through ruptures in the skin, caused by the sudden swelling of the creature. However, Fuchs more frequently saw the droplets in portions of the skin that were entirely uninjured, and was convinced that they exuded through pores. The exuded drops coalesce, congeal, and thus form a covering over the dead female. In the construction of this protective covering, the cuticle, as well as the remnants of the larval skin, the epidermis and the scanty remains of the musculature, are also closely cemented and bound together; the earlier gall-like masses from the vulva (Pl. V, fig. 8*d*) have partially assisted, the final result being the brown cyst which surrounds the now completely dead body. This brown cyst no longer shows signs of life. It is only a protective sac capable of resisting climatic influences for a long time. Its contents, the eggs, in this manner are enabled to retain their viability and power to develop, while if unprotected they would in winter come to an untimely end. Although the cysts possess the special function of overwintering the nematode, they could not be called winter cysts, because cysts also are formed, though in smaller number, in summer.

PERIOD OF CYST FORMATION.

After a study of Chatin's work, Fuchs made experiments during the entire summer and autumn. On each occasion a large quantity of soil, containing numerous nematodes, was thoroughly mixed with water. After allowing the mixture to settle, the supernatant water, containing an abundance of eggs, larvæ and cysts, was filtered through glass wool. Larvæ and eggs passed through, but the larger females and cysts were retained. Some of this larva-bearing fluid was then poured over a pot of sterile soil, in which *Sinapis alba* was already in leaf. The larvæ were retained in the soil, and, finding in the young, tender plants the desired food, went through their normal development. Since this soil had contained no cysts, and since none were introduced, every cyst found there, after a shorter or longer time, must have originated from the introduced larvæ during this vegetative period.

Thus Fuchs planted, infested, and examined a large number of pots, and by careful counts computed the percentage of cysts and females in them. That the numbers thus obtained should possess a wide range of probable error is easy to understand, since it is very easy to overlook the tiny females and cysts in the washings of infested soil. The numbers were determined in the following manner: At a time when the females were easily recognizable, exactly half the plants and half the soil from each pot were taken and examined. The pot was then filled with sterile sand and, after about two weeks, the cysts which had developed in the soil left in the pots were separated by washing and counted. Test counts showed that as a result of a uniform sprinkling of the whole surface of the soil in the pots with the larva-bearing fluid, each plant is attacked in a fairly equal degree. He was, therefore, able to employ this method.

Fuchs was not able to make a simultaneous count of both females and cysts in a thorough manner because up to the time of the maturity of the female the cysts are not to be recognized as such. On the other hand, until the cysts have developed, the females are in a condition easily to be destroyed.

In July eight pots were examined. No cysts were found in three of them; in one pot one, in each of two pots two; in one pot three, and in still another pot five cysts were found. These pots were prepared on June 2 and examined on July 4 and 19.

In August, 10 pots which had been prepared on July 8, were examined. In these pots the percentage of cysts already was much higher. The examinations were made on August 6 and 20. In September similar results were obtained. The pots were prepared on August 3 and examined on September 7 and 23. Quite different results were obtained in October. These pots were prepared on September 2 and examined on October 8 and 25.

The results of these three tests are shown in Table III.

In November several pots showing cyst development which might be considered normal for autumn were examined. The eggs of all females that had not progressed further toward the cyst stage had perished. These pots were prepared on October 3 and examined November 9 and 19.

These examinations clearly showed that cyst formation never entirely ceases; that even in summer some are formed, and that the number immediately increases upon the approach of unfavorable weather. Temperature is thus seen to be a dominant factor. Table V shows that the summer of 1910 was extraordinarily cool, which explains the relatively high number of summer-formed cysts. Fuchs believed that this number would fall off considerably during a normal summer, and if the temperature and moisture conditions were optimum for the Heterodera it might even sink to zero.

On the other hand, the fact that not all females are changed to cysts in autumn is not to be otherwise explained than that in many cases the incrustation and inclosing of the female with the droplet-formed, brown secretion has not been profuse enough long to resist the weather.

Once formed, these cysts remain loose in the soil, the rootlets from which they have fallen having long ago disintegrated, but no change is to be observed in the cyst, either in size or color. Neither do the contents of the cyst show signs of further development during the winter. The eggs fill the cavity of the cysts without any perceptible change and remain protected from all external, injurious influences.

The researches of Liebenberg have shown that cold is unable to injure cysts or their contents.

The parasite is more sensitive to heat. In order to discover a means of combating the parasite Fuchs made exact experiments in this direction. It avails little to kill merely the wandering larvæ with chemicals or low temperature, or to catch them in plants, if the cysts are allowed to remain and each year produce new broods of larvæ. Therefore, an effective method must also destroy cysts and contents.

EFFECT OF HEAT ON THE CYSTS.

Both the effects of low temperatures and of heat applied for various periods of time were studied.

Small flowerpots were filled with soil badly infested with nematodes. These were placed in a thermostat for 6, 12, 24 and 48 hours at constant temperatures. Two series of experiments, employing moist and dry soil, respectively, were carried on. After each treatment every pot was sown with white mustard, whose seedlings were examined three weeks later. A control pot for each set indicated the normal development of the larvæ.

The following results were obtained. A temperature of 30° C. had no apparent effect on the development of the larvæ, which were just as numerous and well developed as in the control pot filled from the same lot of soil and kept at the temperature of the room.

A temperature of 35° C. for six and twelve hours showed no effect. An exposure of 24, and still more, of 48 hours, showed that though the number of nematodes was not changed, the development of the larvæ was greatly affected, and after the lapse of three weeks Fuchs was unable to find a single flask form, while many were to be found in the control pot.

Table III.—*Number of female nematodes and cysts in August, September and October, 1910.*

	Examination made August 6 and 20 (pots prepared July 8).				Examination made September 7 and 23 (pots prepared August 3).				Examination made October 8 and 25 (pots prepared September 2).			
			Females changed to cysts.				Females changed to cysts.				Females changed to cysts.	
Pot No.	Females.	Cysts.	Single pot, percent.	Average, percent.	Femlaes.	Cysts.	Single pot, percent.	Average, percent.	Females.	Cysts.	Single pot, percent.	Average, percent.
1	52	6	12	7	27	3	11	9	19	8	42	33
2	41	2	5		41	5	12		23	7	30	
3	57	4	7		35	4	11		27	5	18	
4	35	3	9		23	3	15		12	5	42	
5	38	5	12		29	2	7		31	9	29	
6	42	3	7		18	2	10		24	8	33	
7	67	2	3		24	1	4		17	7	41	
8	56	1	2		19	0	0		22	9	41	
9	48	4	8		32	4	13		28	6	22	
10	43	3	7		28	3	10		23	8	35	

This was still more conspicuous at 40° C. The pot exposed to this temperature but six hours showed no appreciable effect, but the effects were perceptible after twelve hours, while in twenty-four hours an appreciable reduction in the number of larvæ was to be seen, and all were much retarded in development. After an exposure of 48 hours the pots containing dry soil showed only a few small larvæ, while those containing moist soil, after repeated examination, revealed no living nematodes.

The next experiment showed that even a temperature of 45° C. did not suffice to kill all the nematodes, for larvæ could be seen in all the pots, though their number was small.

Pronounced results were obtained by heating the pots to 50° C. for six, twelve and twenty-four hours, which, according to the length of exposure, caused a greater or less reduction in the number of larvæ, as well as a greater retardation in their development. In the pots of dry soil, exposed for forty-eight hours, only a single larva was discovered; in the pots of moist soil, exposed for the same period, none were found, even after repeated examination.

At a temperature of 55° C. an exposure of twenty-four hours sufficed to destroy all nematodes; six-hour and twelve-hour exposures permitted the survival of a few.

At 60° C. no larvæ were to be found after a six-hour exposure.

These experiments, therefore, show that the contents of the cysts of *Heterodera schachtii* are destroyed by an exposure of forty-eight hours at 50° C., of twenty-four hours at 55° C., of six hours at 60° C. but that a temperature of 35° C., and still more, a temperature of 40° C. are capable of considerably reducing the number of nematodes.

TABLE IV.—*Number of female nematodes and cysts in November.*

Pot No.	Females.	Cysts.	Females changed to cysts. Single pot, percent.	Females changed to cysts. Average, percent.
1	22	13	59	66
2	26	18	69	
4	20	15	75	
5	17	12	71	

In this case, about 34 percent perished without having been able to assume the preservation form.

TABLE V.—*Daily mean temperatures (° C.), during observations of Fuchs, Vienna, March 1 to November 20, 1910.*

Day of Month.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.
1	6.8	1.4	8.2	19.0	17.0	21.4	12.3	16.3	10.9
2	7.1	3.4	7.8	20.5	18.4	21.1	12.8	12.8	8.2
3	3.7	5.1	4.5	21.1	15.9	21.3	13.0	13.5	4.6
4	2.6	6.3	5.9	22.3	14.1	17.7	13.0	12.5	8.0
5	3.0	8.8	7.0	21.5	14.6	15.1	11.7	10.7	8.2
6	4.3	10.1	9.5	18.8	14.4	14.1	11.4	10.4	6.0
7	5.1	10.2	11.6	19.1	15.1	15.6	13.4	10.1	6.9
8	2.0	9.2	7.1	19.3	15.3	17.2	14.4	12.7	7.5
9	2.3	9.3	8.4	21.5	14.1	17.9	12.2	14.5	9.3
10	4.9	7.1	10.1	21.3	18.2	15.8	14.5	13.6	6.1
11	7.1	3.7	15.6	20.7	16.8	15.9	14.2	13.7	4.0
12	7.4	5.4	11.7	19.4	18.6	17.3	15.8	13.0	4.5
13	8.4	9.4	14.4	17.5	19.4	18.5	17.0	12.8	3.8
14	8.4	12.8	15.9	16.2	19.1	16.9	16.4	9.7	4.2
15	8.1	15.7	17.6	17.4	17.0	15.9	16.1	7.2	5.6
16	8.3	13.9	16.5	17.0	20.5	17.6	14.9	8.2	5.2
17	8.9	10.5	16.8	16.2	22.1	19.8	14.5	7.6	3.8
18	8.7	3.7	19.0	17.3	21.1	19.8	12.0	7.9	3.3
19	6.5	11.8	20.3	17.7	20.9	21.9	12.9	10.0	1.8
20	4.1	11.5	20.0	13.9	18.3	21.1	13.0	7.0	1.6
21	5.4	9.4	18.9	12.5	18.9	21.9	10.8	9.2	...
22	6.2	10.9	16.9	15.7	24.5	21.3	8.0	10.1	...
23	5.1	5.6	14.9	16.8	19.6	16.4	9.0	8.9	...
24	3.6	8.6	14.3	17.0	13.5	16.0	11.5	7.5	...
25	5.3	10.0	15.4	18.3	17.1	16.6	12.0	6.9	...
26	5.5	12.1	17.1	17.4	16.9	18.1	11.1	6.5	...
27	5.9	9.4	16.8	14.2	16.4	17.4	12.5	8.0	...
28	8.2	9.6	15.9	18.1	17.3	16.4	14.4	8.0	...
29	4.8	12.2	17.0	19.7	18.9	....	14.0	7.4	...
30	1.7	11.6	17.8	18.1	20.2	....	12.5	7.9	...
31	0.5	....	18.0	....	21.3	15.0	....	9.2	...

Whether the soil be moist or dry during this heating, according to the observations of Fuchs, seems to matter little. These experiments make it appear that the cysts are better able to withstand the higher temperatures if they have not absorbed too much water, and when, as is probably the case in dry soil, they possess a small water content.

In order to ascertain the degree of temperature required to kill nematodes in a short time, Fuchs put some badly infested soil in large test tubes, heated these in hot water to different degrees, and read the temperature of the contained soil on a thermometer thrust into the soil in each tube. The soil thus treated was mixed with sterile soil in small pots and sown with *Sinapis alba* in order to be able to determine the presence of live larvæ.

In this manner soil was heated to 60° C. for one, five and ten minutes, respectively. In the first set of experiments, despite careful search, no larvæ were found. On repeating them, several larvæ were found in the 1-minute and 5-minute tests. In the third trial several larvæ were found in the 1-minute exposure. After a long search just one larva was found in the tubes exposed for 5 minutes, and 2 minutes at 60° C., while in that exposed to the same temperature for 10 minutes an oft-repeated search revealed no living larvæ.

The experiment at 62° C. showed that a heating of four minutes left two larvæ. Each longer exposure—two, five and ten minutes—entirely rid the soil of nematodes.

A heating of the soil to 63° C. for but one minute unfailingly killed all nematodes. This experiment was repeated ten times with like results. Also, in this experiment, as soon as the thermometer indicated 63° C. and the tube was withdrawn, it was found that, though the temperature at once began to fall, the nematodes had been killed.

Therefore, a soil temperature of 63° C. sufficed to kill all nematodes, because at this temperature both cysts and contents were destroyed. According to Strubell and Vanha, the larvæ, as well as the males and females, succumb at a temperature of 35° C.

These experiments may then suggest a method of combating and destroying *Heterodera schachtii*—a method already applied in a simple manner by Kühn in his soil-burning experiment. According to Fuchs, the question remaining is simply how to heat the upper stratum of soil to 63° C.

DEVELOPMENT OF THE CYST CONTENTS.

To return to the biology of the nematode: Upon the melting of the snow and the arrival of warmer days, life begins to reveal itself in the cysts. The eggs progressively develop, and, as soon as moisture and temperature are sufficiently favorable to enable free-living larvæ to endure the conditions without injury, it may be observed that from one egg after another serpentine larvæ emerge and are free to pursue their way. Should the cyst still be young, this happens chiefly through the vulva, but with old cysts the larvæ often escape through tears and cracks in the brown hull, to begin their search for the fine rootlets of their host plants.

The problem now to be solved was whether a young or just-formed cyst is immediately in a condition to liberate living larvæ, or whether a certain time must elapse to allow the eggs to mature to a degree where the young embryos might escape from them, then from the cysts.

Attention was especially devoted to cysts which, according to the observations of Fuchs, had been formed during the summer. Although not very numerous, they were entirely sufficient to allow him always to have some for both microscopic and experimental work. The microscopic examinations showed that eggs were present in all stages of development, the first stage naturally predominating. These had cloudy, nucleated contents, and were estimated at two-thirds of the whole. In proportion, eggs were present which clearly showed the spiral embryo, as well as those from which larvæ were ready to escape. In order to determine whether these scarcely completed cysts might already be in a condition to set larvæ free, some of them were covered with soil near seedlings of white mustard in pots filled with sterile soil. These cysts were obtained by the rinsing method from badly infested soil and were separated with the greatest precautions with a fine brush in order to avoid the least injury. The plants were examined after three weeks. In each of three trials nematodes were found to have attacked the roots. They could not have originated elsewhere than in the cysts formed but a few weeks earlier.

From this it may be seen that cysts formed in bad weather are capable of liberating larvæ, presuming weather conditions to supervene which might render their emergence possible.

These facts now raise the question: How is it possible for cysts that may be a whole series of years old to retain viable eggs? Why have the larvæ not long ago escaped?

AGE OF THE CYST.

To answer this question one must be assured of the age of particular cysts, or what is more to the point, how long the host plants must be kept from the fields to destroy the nematodes through starvation.

Fuchs stated that he had not sufficient material at his disposal to give a conclusive answer.

This is certain: After a period of five years, during which the land in question was not cultivated, and from which weeds were kept with the utmost care, a considerable number of egg-bearing cysts remained. Larvæ emerged from these and immediately attacked host plants. This land, which remained uncultivated for five years, in which beets badly infested with *Heterodera schachtii* had been grown, was the oldest fallow ground Fuchs had at his disposal. He could only estimate, from its condition and the number of cysts present, that a period of at least eight years is necessary to destroy nematodes in a field by withholding host plants.

The result of microscopic investigations on these 5-year cysts, as well as on the 3-year and 4-year ones, taken for comparison, offers a suggestion toward a solution of the problem as to whether the cysts, during their whole existence, gradually allow the liberation of their contents, or whether each cyst has a particular time for maturing, lasting from a few weeks or days in most cases, to years in many others. In this case there must be present, for example, 4-year cysts that still completely retain their entire contents of 350 to 400 eggs. There might be cysts with a maturing time of even four years, having the function of retaining in the soil Heterodera larvæ for so and so many years.

A large number of 3-year, 4-year and 5-year cysts were examined and compared with 1-year, 2-year and absolutely fresh ones. On the evidence of these examinations it can confidently be stated that the "simultaneous development" (*eben Entwicklung*) hypothesis must be false. At the close of a period of five years there is no longer a single cyst in the ground that retains its entire contents. On the contrary, they are almost empty, only a small proportion of the eggs remaining in the cysts. This may easily be seen if a number of 1, 2, 3 and 4-year cysts are placed beside each other under the microscope. It was thus possible to show an almost exact gradation. Single cysts were carefully cut, their contents examined and the number of eggs and larvæ ascertained. Naturally some eggs were damaged and larvæ were liberated in the operation, on which account only the total number of eggs and larvæ will be given.

Fuchs examined sixty 5-year, forty 4-year and ten 3-year cysts. Among the 5-year cysts 55 percent were found completely empty, containing neither eggs nor larvæ; 45 percent still retained living contents, whose number ranged from one egg (in one case) to fifty-three eggs and larvæ in another. The rest always had fewer than 50 — 10 to 20 eggs in 35 percent of the cases; two cysts contained more than 25 eggs, viz., 53 and 32; the rest contained less than 10 eggs each. Almost all the cysts seemed to be much shrunken, torn and often hanging in tatters, and the farther the erosion had proceeded the smaller the number of eggs that remained.

A similar but not so marked a picture was presented by the 4-year cysts. It could be demonstrated that, although most of them were shrunken and apparently eroded, they looked much better than the 5-year cysts. About 20 percent of them were empty and the maximum was 112 eggs and larvæ in one cyst. About 40 percent contained 30 to 45 eggs and larvæ, while 6 percent contained more than 45 and 9 percent less than 30 eggs and larvæ. A picture corresponding in degree was presented by the 3-year cysts, which contained an average of 40 to 50 eggs and larvæ, with a maximum of over 160 in one case. When it is recollected that fresh cysts contain 400 eggs, the gradual diminution in number may be realized, and one may conclude that the larvæ gradually (progressively) emerge from the eggs until finally only the shrunken, tattered and completely empty skin of the cyst remains. This is then disintegrated by the weather.

Fuchs could not find any conclusive explanation why some eggs in the same cyst mature early but others much later. He took cysts, apparently alike, placed some in a 0.75 percent solution of sodium chlorid, others in a mixture of that solution and the expressed juice of young mustard plants, but absolutely no difference could be observed in their development. At one time here, at another there, more larvæ had emerged, but it could not be seen that any effect was produced by the addition of plant juices. The concentration was modified, at one time using much diluted, at other times almost pure plant juice, but equally without result. Likewise, when he made these experiments in the moist chamber whole plants of white mustard were laid on the microscope stage beside cysts; others were placed there without plants, but no difference in their behavior could be discerned. On the following day a larva had pierced a rootlet and three were at large near by. Cysts remote from plants had released seven larvæ. Numerous repetitions gave equally negative results. He therefore believed that larvæ emerge a few at a time, as they mature and as temperature and moisture conditions are favorable, and that the presence of host plants is not a factor of any consequence in causing the emergence of the larvæ.

PERIOD WHEN LARVAL WANDERING BEGINS.

In the climate of Germany the period at which larvæ begin to emerge, when the great wandering in search of food commences, and when propagation takes place, had hitherto remained unknown. To determine these points Fuchs again had recourse to the washing method. At the beginning of the season portions of soil were washed from week to week. In this operation special care was employed to avoid crushing the cysts, and in this manner a mechanical separation of the eggs also was avoided. After allowing the material to settle the turbid water was filtered through glass wool and the small cysts, as well as the larvæ that might be present, passed through. For the experiment he took large boxes in which beets and mustard had been planted and in which nematodes abounded, ascertained the temperature, removed the upper three centimeters of soil and then made a soil test. The larva-infested water that flowed off was poured over a flower pot filled with sterile soil, in which were plants of white mustard two days old; therefore, the larvæ had opportunity immediately to seek suitable host plants and continue their development. In three weeks the plants were examined, as were also the control pots, which had been sprinkled with water containing larvæ washed from nematode-infested soil, out in the warmth. The experiment was begun near the end of February. The examinations made in the first two weeks still showed negative results. Another test was made on March 12. The soil temperature was 7° C. at a depth of 20 centimeters. The mean daily temperature was 7.4° C. An examination made after three weeks revealed larvæ that had traveled, an evidence that by March 12 the larvæ had crept forth, and had begun their travels in the soil. Similar results were obtained from examinations made on March 14, 22 and 28, although cold weather returned, with a consequent setback. At the end of March and the beginning of April the ground was covered with snow. The examination made April 1 showed that on this date, with a mean temperature of 1.4° C. and a soil temperature of 5° C., no viable larvæ were to be found in the soil. However, things appeared quite otherwise on April 5. At this time the mean temperature of the air was 8.8° C. and of the soil 6.5° C. Numerous larvæ were found in the soil, and similar results were obtained the following week.

Warm weather intervened and Fuchs was able to find wandering larvæ in the soil throughout the summer, whereby he observed that at high temperatures (15 to 21° C.) the number became much greater. In mid October, when the temperature had begun to fall considerably, there was a perceptible diminution in the number of wandering larvæ in the soil. The wash test of October 24 (the soil temperature being 8° C., mean air temperature 7.5° C.), when applied as before, resulted at the end of three weeks in the finding of seven larvæ among 20 plants. Still fewer larvæ were found in a search of November 3, only two being found among 20 plants. On this date the mean air temperature was 4.6° C., and the soil test was made at a temperature of 5.5° C. This experiment was repeated on November 8. The soil test was made at a temperature of 6° C. with a mean air temperature of 7.5° C. In spite of prolonged and repeated search no larvæ were found. Similar negative results were obtained on November 11 and 15. From this it appears that the travels of young larvæ cease as soon as the temperature falls to 6° C. or less.

It has been demonstrated that nematode larvæ can quite easily continue to exist at a temperature of 6° C., although their movements are then greatly reduced and their whole life energy seems to fall to a minimum. They appear to become benumbed with cold, but the higher the temperature rises the quicker and stronger become their movements. At 6° C. their vital energy sinks so low that their movements are no longer sufficient to liberate them from their prison, the cyst. They can not push their way through the narrow opening, but remain enclosed by the protective hull of their dead mother, to their own advantage. But if, despite the low temperature, they should gain their freedom, they would probably succumb, because their movements are too feeble to enable them to penetrate the rootlets.

Table VI.—*Mechanical analyses of types of soil employed by Fuchs.*

Soil particles.	Sandy soil.[1] Per cent.	Loam.[2] Per cent.
Grains with a diameter of		
Less than 0.01 millimeter...	10.50	43.34
0.1 to 0.05 millimeter......	12.36	24.92
0.05 to 0.1 millimeter.....	21.94	13.84
More than 0.1 millimeter..	55.20	17.90

BIOLOGICAL VARIETIES OF HETERODERA SCHACHTII.

Although *Heterodera schachtii* is seen to be polyphagous, it appears to be true of it, as of *Tylenchus dipsaci,* that it may become specially adapted to certain host plants. Its recurrence on the same species in similar soil may so specialize it as to constitute a variety (Marcinowski, 1909). This may proceed so far that nematodes that have for generations been restricted to a particular host plant become so much adapted to it that its transference to another host plant may be only partially successful or fail entirely. It is probably most injurious to the plant to which it has become adapted. Possibly this has not gone as far with *H. schachtii* as with *T. dipsaci.* Liebscher (1890, 1892) found that nematodes on peas and vetch on the one hand and on oats and beets on the other were differentiated. Nematodes from oats and beets produce rather larger eggs, somewhat larger larvæ and much larger and shorter necked females; the former also lack the "subcrystalline layer" (last larval cast of the female, which often in fragments covers the adult). The two forms were also biologically differentiated. Oats which had been sown in beds infested with pea nematodes showed no signs of being attacked by them. The converse was equally true. Liebscher further found that pea nematodes may be transferred to vetch and horse beans, but not to beets, oats, rape, cabbage, mustard, turnip, etc. He considered the pea nematode to be a variety of *H. schachtii,* and believed it capable of returning to the original form, despite the opinion of Hollrung to the contrary. Liebscher (1890, 1892) did not give sufficiently accurate measurements, simply stating that the pea nematode had a smaller body and longer neck than the beet nematode. However, Voigt (1892, 1894) was more exact in his description of oat and beet nematodes, giving the measurements shown in table VII, which also shows measurements given by Marcinowski.

According to these measurements, the beet nematode is rather longer and relatively much thicker, with a neck both actually and relatively shorter than the oat nematode. However, Marcinowski (1909) did not think these measurements sufficiently numerous, neither did she know how many generations each variety passed through on the respective hosts. She considered it quite probable that greater differentiations would have developed in the course of more generations. Voigt (1894), as well as Liebscher (1890, 1892), demonstrated that biological forms exist, and that nematodes from oats and beets were not mutually interchangeable. Whether the nematodes may or may not be transferred from one host to another would appear to depend on the degree of adaptation that had already taken place; in other words, on the number of generations borne by a particular host plant. (See Kühn, 1874.) Kühn in 1881 showed that while beets were regularly injured in nematode-infested land, oats were at one time strikingly sensitive to the worms and at another time were free from attack. He was not prepared to explain this. Reciprocal transfer of oat and beet nematodes succeeds easier than that between legumes and oats, or legumes and beets. This is supported by the experience that oats do well on nematode-infested ground if they follow peas or beans. Thelen (1904) spoke of the existence of varietal differences between beet and pea nematodes. Peas sown in ground infested with beet nematodes were at first free from attack, but after several crops of peas had been raised on the same ground the roots of the later crops became infested. It would appear from this, thought Marcinowski, that the nematodes simply required plenty of time in order to become adapted to a new host. Thelen, however, could not agree with this idea. Marcinowski thought it would be very profitable to carry on experiments with many generations of nematodes in order to settle this question. Of *Heterodera radicicola,* Bessey (1911) states he has been "unable to detect special adaptation to any one species of plant."

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[1] Water capacity, 38 per cent of weight of dry soil; organic substance, 2.06 per cent.

[2] Water capacity, 34.7 per cent of weight of dry soil; organic substance, 4.4 per cent.

Fuchs (1911) made observations to the effect that quite probably races of nematodes might be developed through adaptation to a particular host plant, after feeding exclusively on the one host plant for a series of years. But such a condition is not met with in practice. Oats are mentioned as the conspicuous example. In regard to the attempted explanation of the fact that oats are at one time attacked as badly as beets, but at another time, in soil just as badly infested, are not attacked at all, or very feebly, he says:

"One does not plant oats after oats, and today it is seldom that beets are grown uninterruptedly for years. It would be difficult in nature to produce a pure oats or beets race. We have to do with a mixture of both races, a transition form, which soon tends in one or the other direction. However, the appearance of *Heterodera schachtii* on oats is so irregular that the formation of varieties can scarcely be explained in this way. Nematodes that I have found in my experiments thrive equally well on mustard, beets and oats. Once, in June, 1910, I replanted a pot of badly infested soil with oats, but not a single larva was to be found on their roots. Some rows of beets and mustard were sown between the rows of oats; the roots of the two latter plants became filled with larvæ. In this case we can gain no explanation for the formation of a race appearing only in oats. It can only be concluded that a mixed form exists in fields, which can attack either oats or beets, but which, however, if it should have access to but one kind of host plant, would gradually become so accustomed to such a host that probably a race might be produced."

TABLE VII.—*Measurements of beet and oat nematodes, according to Voigt and Marcinowski.*

Dimension relations.	Beet nematode measurements. Number.	Actual.	Average.	Oat nematode measurements. Number.	Actual.	Average.
Measurements by Voigt:						
Size of female, millimeters	..	0.6 to 1.00	....	..	0.5 to 0.8	....
Thickness of sub-crystalline layer, millimeters	..	.01	....	..	.04	....
Measurements by Marcinowski:						
Female—						
Length, millimeters..	17	.39 to .88	....	10	.4 to .78	....
Length/Thickness ....ratio	17	1.26 to 1.97	1.55	10	1.57 to 2.2	1.93
Spear length, mill'rs.	6	.016 to .029	.02	10	.09 to .028	.023
Neck length, milli'rs.	17	.05 to .16	.09	10	.09 to .16	.12
Length/Thickness ....ratio	17	4.6 to 10.8	7	10	3.3 to 7.7	5.38

OVERWINTERING OF THE BEET NEMATODE.

Wimmer (1906) conducted pot experiments in which small pieces of nematode-infested beet rootlets were mixed with soil composed of sand and peat. By the application of hydrochloric acid this soil had been deprived of most of the soluble mineral plant foods. These pots were put in a cool place for the winter. The following spring it was found that larvæ had developed quite normally, the soil being abundantly sprinkled with live nematodes. An examination showed an average of 10 per 0.5 gram of the soil.

Vañha and Stoklasa (1896) showed that the egg can not withstand any degree of frost. But the adult may be exposed to frost on the surface of the ground without apparent injury.

Wimmer (1906) also stated that in autumn larvæ penetrate the roots of winter rye and early the following spring are metamorphosed into the adult stages.

In this respect it would appear to resemble *Heterodera radicicola,* of which Bessey (1911) says:

"In the roots of perennial plants, for example, European grape, fig, etc., the writer had frequently found living female nematodes in nearly or quite complete development at various periods of the winter and early spring, showing that in such roots the nematodes may survive, not only in the larval stage, as previously described, but also as mature females, ready to begin egg laying as soon as the weather becomes favorable."

These conclusions do not seem to receive the support of Fuchs (1911), who says of the brown-cyst stage of the pregnant female, so carefully described by Chatin (1887, 1888), that it is the resistant stage of the worm. According to Fuchs, as already shown in detail, it can overwinter without plant food, and even should host plants fail during the following warm season, it may remain in the soil a whole year until suitable plants shall enable it to produce new generations and new preservation forms. Not every female enters into this cyst form. His observations also led him to the conclusion that not all the eggs of a cyst are hatched at once, but that the larvæ emerge a few at a time, according as they reached the proper stage of maturity, and as suitable temperature and moisture conditions obtained. The presence of host plants did not appear to be an important factor in the emergence of the larvæ. He states, further, that the eggs and free living larvæ succumb to the cold and other unfavorable conditions incidental to autumn and winter. On the other hand, low temperatures do not seem to affect the brown cyst or its contents. It is more readily affected by high temperatures. This writer found that a soil temperature of 63° C. is sufficient to kill both cyst and its contents. He also found that a considerable number of the brown cysts survived in soil not cultivated meantime, but carefully kept free from weeds and other plants for five years, and under favorable temperature and moisture conditions gave birth to larvæ, which then attacked cultivated host plants. He concludes from these observations that a rotation period of not less than eight years should be practised in order to insure a complete riddance of the beet nematode from infested soil.

From these rather conflicting observations one may suspect that in the experiments of Wimmer he had some of the cysts among his rootlets, or that at least some of the females assumed that stage after they were placed in the pots, and that these survived the winter and gave birth to the free-living larvæ seen by him. On the other hand the limiting low temperature may not have been reached, so that free-living forms of the nematode as well as brown cysts may have been enabled to survive. It is also possible that larvæ may survive the winter, if embedded in the root tissues of their host, under temperature conditions that would kill them were they scattered in the soil, but of this we have no positive evidence. The experiments of Fuchs show unmistakably that in the brown cyst we have the preservation form of the beet nematode—a condition in which it can not only withstand the rigors of winter, but also considerable degrees of heat: a state in which it is not soon destroyed by lack of moisture, as is so conspicuously the case with all the free-living forms.

DISTRIBUTION OF HETERODERA SCHACHTII.

In Foreign Countries.—Beet nematodes have been found on sugar beets and other plants in the following countries: Germany, Austria-Hungary, western Russia, Holland, Belgium, France, Denmark, Sweden and the Azores. (Sorauer, 1906.) Apparently *Heterodera schachtii* is native to Europe, although, since it is closely related to *H. radicicola,* it is possible that, as is probable with the latter, it was introduced on plants imported from the Tropics over a hundred years ago, when a general trade in exotic plants began. (Bessey, 1911.)

In the United States.—Bessey (1911) states that in 1907 (Fig. 2) he found the beet nematode in California, near one of the oldest beet sugar factories in the United States. In this vicinity were some fields in which (1907) sugar beets had been grown 37 years in succession. They were not yielding one-tenth of a normal crop, and were terribly infested with beet nematodes. These eel worms were present also in all fields within a radius of a mile. In fields farther away, which had been in cultivation only a few years, they were not found. One field near a second sugar factory in the same state was found to be badly infested and yielding about one-fourth of a normal crop. The slow spread of the pest was ascribed to drought and the stiffness of the soil. This nematode was reported near a third factory, and was found also in several fields near an old-established factory in Utah, as well as later being found very prevalent in districts located several miles from that factory. The agriculturist of the Utah factory said he had observed similar trouble in beet fields for 12 or 14 years prior to 1907. This nematode was found also in a restricted area in a field near another old beet sugar factory in Utah.

During the summer of 1912, Mr. L. P. Byars[1] made a survey of the United States, in collaboration with the Office of Cotton and Truck Disease and Sugar Plant Investigations, to ascertain the present distribution of both root-knot and beet nematodes (Fig. 3). He reports having found the beet nematode in an 80-acre field about two miles from a sugar factory in the southern part of California. In another California beet district three ranches were found to have nematode-infested patches. On one of these farms, about two years ago, approximately one-third of an acre, last year half an acre, and this year two acres of beet land had become infested; thus showing the rapid spread of the pest after it had become well established. The beet nematode was found on one ranch in a third beet district in that state, where beets had been grown successively for twelve years. Another field where they had been raised only two years also was infested, but in a less degree. On what is known as Martin's Island ranch, near Spreckels, Dr. Albert Schneider in 1906 noted and probably made the first record of the occurrence of the beet nematode in the United States, and the pest is still found there.

Many fields near the above mentioned sugar factory in Utah, especially where beets had long been cultivated, were found to be badly infested. This was true also of one of the outlying tributary districts.

INTRODUCTION OF *Heterodera schachtii* INTO THE UNITED STATES.

Practically all beet seed at present used in the United States is imported from Europe. Since beet seed, with its rough surfaces, is admirably adapted to afford hiding places for minute objects, including fungous spores and creatures as tiny as nematodes, it may be reasonable to conclude that the beet nematode had been introduced into this country upon sugar beet seed. The fact that the pest has been found only in the oldest beet districts of the United States might be looked upon as supporting that idea, when it is considered that the presence of the nematode would only make itself apparent, to any serious extent, after a number of years.

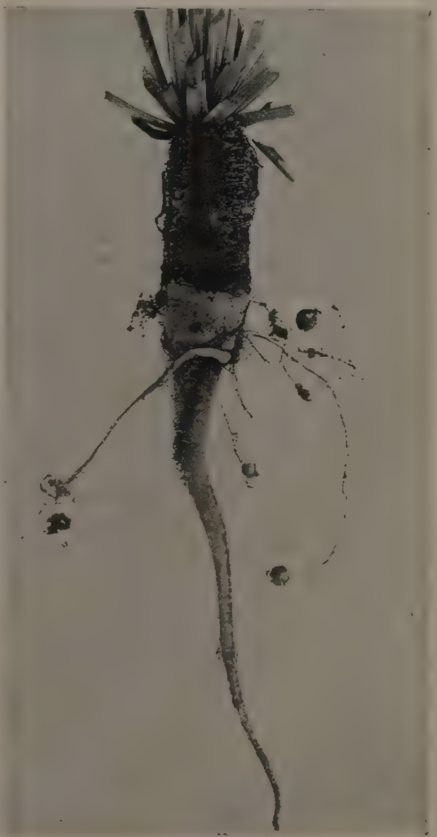

PLATE VI.

Knots on rootlets of a sugar beet caused by Heterodera radicicola. (Photographed by Dr. Charles O. Townsend.)

That any of the free-living forms of this nematode should thus gain entrance is doubtful. There is considerable evidence against such a view. According to several observers, the free-living forms of *Hetero-*

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[1] Unpublished notes and correspondence with the author.

dera schachtii are unable to endure any degree of desiccation. Marcinowski (1909) states that this nematode is very susceptible to drying. Strubell (1888) placed nematode larvæ on a microscope slide and covered them with a layer of water. The water was allowed to evaporate gradually, leaving the larvæ dry about one hour. After this they failed to revive upon the addition of more water.

However, circumstantial evidence is forthcoming tending to support a belief that even the free-living forms, at least the larvæ, may have been carried into this country in a viable condition with beet seed. There is also the possibility that larvæ may be preserved in the small lumps of soil that frequently are found in sacks of beet seed. In this connection Bessey[1] states:

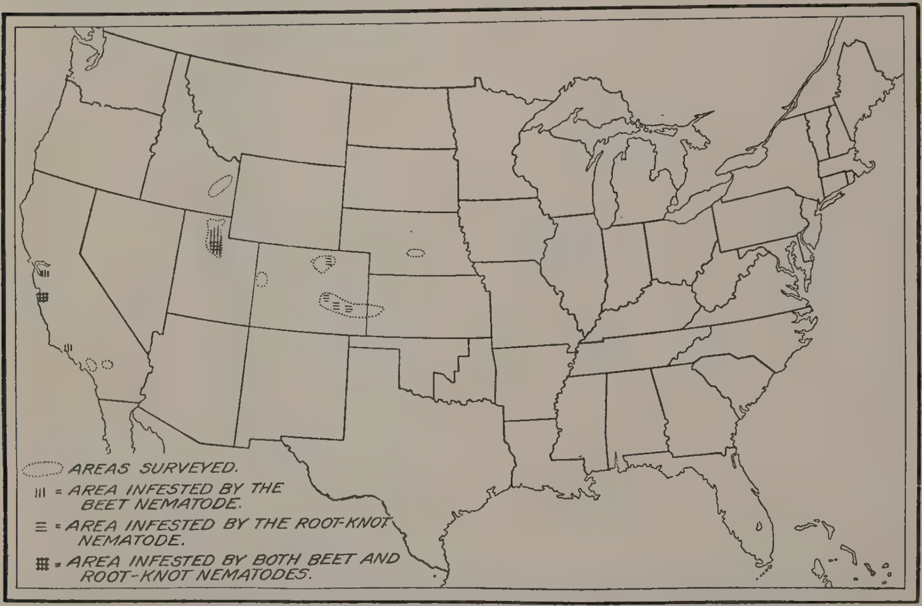
AREAS SURVEYED.
||| = AREA INFESTED BY THE BEET NEMATODE.
≡ = AREA INFESTED BY THE ROOT-KNOT NEMATODE.
# = AREA INFESTED BY BOTH BEET AND ROOT-KNOT NEMATODES.

FIG. 2. KNOWN DISTRIBUTION OF THE ROOT-KNOT AND BEET NEMATODE, ACCORDING TO THE SURVEY OF DR. E. A. BESSEY (1907).

> It is a well-known fact, and one that I have ascertained in conversation with the agriculturists of various beet-sugar companies, that in every sack of beet seed there are larger or smaller amounts of dirt. Sometimes this dirt is in the form of fine dust, but on the other hand it may be, and often is, in the form of little chunks, sometimes as big as a small marble. Dr. Albert Schneider, of San Francisco, who was employed by the Spreckels Beet Sugar Co. at the time of making the experiments, moistened up a number of these little pieces of earth and found in them still viable larvæ of nematodes, although I do not think the evidence he had would justify him in saying that these were necessarily the sugar-beet nematodes. However, it seems to me that some of them were sugar-beet nematodes, although it would have been necessary to grow them in contact with beets to prove that. If, then, the source of this nematode is soil mixed with beet seeds, it would seem to be almost impossible to keep them from getting into this country again (since most of the beet-growing districts of Europe, including those where seed is grown, are infested with these nematodes more or less), so long as we have to depend on European sources for the bulk of our seed.

Further evidence along this line is at hand. Miss C. O. Jamieson, of the Office of Cotton and Truck Disease and Sugar Plant Investigations, in a search for organisms on beet seed, discovered, in 1911, live nematodes in the sediment centrifuged from washings of beet seed received in this office from the American Beet Sugar Co. at Rocky Ford, Colo. Live nematodes were discovered in no less than seven different samples, representing six varieties of seed, from four German seed firms. Since the object of the search was not primarily nematodes, these were not identified or preserved. While this evidence may not leave much doubt, it is not proof.* However, it is quite certain that other and equally destructive species of eelworms, such as *Tylenchus dipsaci,* are constantly being introduced upon or with beet seed, since this and some other species are known to be very resistant to desiccation for long periods, then to revive on the resumption of suitable conditions of moisture and temperature.[1]

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[1] Letter to W. A. Orton, Feb. 16, 1912.

*No living beet nematodes have yet been found in such clods of soil. (Nov. 1, 1915.)

Whatever doubts there may be in regard to the introduction of free-living forms of the beet nematode, there can scarcely be any question of the possibility of its introduction in the brown-cyst stage, since this is capable of resisting cold, considerable heat, and dry conditions. It is likely that at no time are great numbers of cysts present among beet seeds, because they could only get among the seeds along with particles of soil that may have adhered to stems or seedballs at harvest time. It would, therefore, probably take many years to infest a field seriously by means of beet seed. In the localities known to be infested in this country, the operation has undoubtedly been accelerated by the fact that, unfortunately, beets have been grown uninterruptedly for years in the same fields. This method would be a certain one in the long run. It would appear that the nematode larvæ observed in the instances just cited may actually have emerged from cysts at a time shortly before the respective searches were made, owing to the temperature of the warehouse or storeroom in which the seed was kept being favorable for the hatching of the cyst-protected eggs.

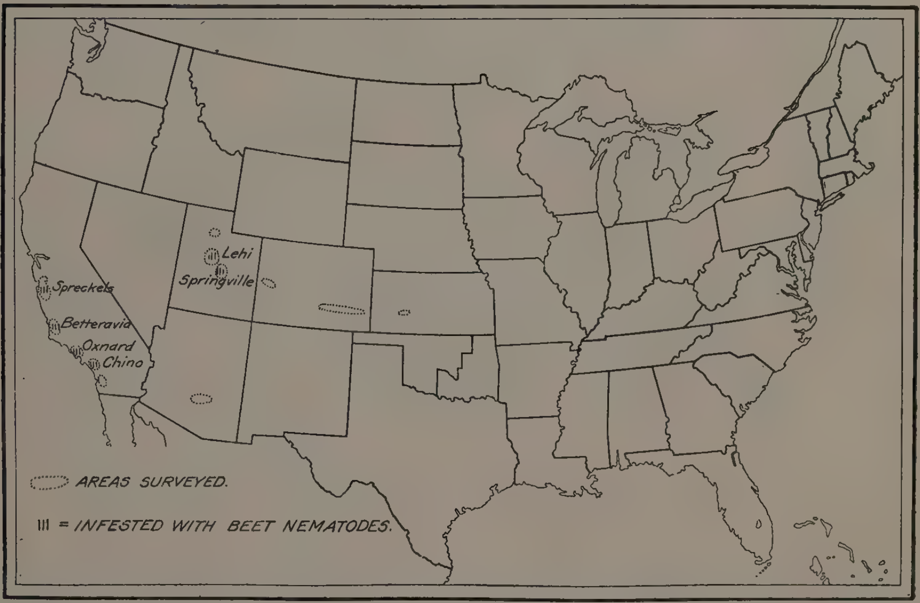

FIG. 3. KNOWN DISTRIBUTION OF THE BEET NEMATODE IN THE UNITED STATES IN 1912, ACCORDING TO THE SURVEY OF L. P. BYARS.

It is almost certain that the beet nematode has been and perhaps is still being introduced, together with the root-knot nematode, with nursery stock. The roots of plants and the adherent moist soil and packing are admirably adapted to convey large numbers of such parasites. Trees, plants, rooted cuttings, bulbs, and potatoes all are probable carriers of the pest. In view of the fact that natives of Germany and other beet-growing countries have immigrated to and settled in the beet-growing districts of the United States, a certain amount of plant exchange doubtless has been carried on between immigrants and their native countries, thus offering opportunities for the introduction of a variety of pests. This whole question needs careful attention and study.

EFFECT OF THE PARASITE ON SUGAR BEETS.

Němec (1911) has studied the effects of nematode attacks on the root tissues. Lateral rootlets infested with mature female nematodes were fixed in Flemming's solution and sectioned in series. He found the conditions described as follows:

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[1] N. A. Cobb in a conversation with the writer, 1912.

At the first glance (Pl. VII, fig. 1) unusually large cells were apparent in the vascular bundles; cells of such a size could not be found in sound rootlets. They were much larger than normal parenchyma cells of the vascular area, and in cross section occupied much more space than the usual elements, which show but a normal amount of variation. A comparison of these modified vascular bundles with normal ones, revealed in the former an absence of the deuteroxylem and frequently an entire lack of vessels with large lumina. There remain but a few vessels with small openings and these are adjacent to the protoxylem. In some places the vessels are crowded together, in others they are dispersed, and often they are thrust out of their normal position by the vigorous growth of the giant cells.

The phloem does not undergo so marked a modification, since it is not so well developed in the rootlets as the xylem. Yet even the phloem may be thrust from its original position and the number of its elements be reduced.

The giant cells seem to remain rich in cytoplasm so long as the worm continues to suck; the granular reticulum becomes fixed, and sometimes the whole cell lumen is filled. In a single cross section one nucleus is generally to be seen in each cell (Pl. VIII, fig. 2), and less frequently two or three appear. The cells adjacent to the buccal opening of the worm contain thread-like mitochondrin. The walls of the giant cells become moderately thickened, with a considerable thickening where they are in direct contact with the vessels (Pl. VIII, fig. 2) and where they actually touch the head parts of the worm.

Strubell stated that the central bundle, which extends throughout the length of the root, always remains intact. Only by the combined attacks of many worms would it be thrust aside.

Němec corroborates this, stating that the head parts of the worm penetrate only the endoderm, or at most, the pericambium, while the inner elements of the plerome remain untouched. Giant cells never originate in the endoderm or pericambium, but mostly in the cells of the adjacent tissues.

In longisection (Pl. VII, fig. 2) it is observed that the giant cells present long, tapering forms, parallel to the long axis of the rootlets. They often cover the entire surface of the vessels and contain several nuclei in their thick plasma. The nuclei are scattered irregularly in the cytoplasm, or are crowded together. They are always larger than nuclei of normal tissue cells. Frequently there are perforations in the length of the cell wall, forming large openings through which the cytoplasm of neighboring cells communicates and through which the nuclei may migrate.

By a study of both cross and longisections it is found that these giant cells form syncytia. Many cells are fused together. The transverse walls almost entirely disappear, but more of the longitudinal walls remain. The cell sheath may be 1 to 2 millimeters long.

The nematode pierces only the external, corky layer of the beet itself. As soon as it has penetrated to the underlying parenchyma cells, the latter begin to enlarge slightly (Pl. VII, fig. 1 and Pl. IX, fig. 1) so that a small swelling or tubercle is formed at the site of the puncture. Cytoplasm accumulates there, and perforations occur here and there in the cell walls. A conspicuous nest of giant cells is thus formed, 0.4 to 0.7 millimeters in diameter, which perhaps becomes a single syncytium.

At the death of the worm, a portion of the cytoplasm partially disappears from the giant cells (Pl. VIII, fig. 1); their membranes progressively thicken and finally die. Since this dead portion communicates (Pl. IX, fig. 2) with the exterior of the root, excellent opportunities are thus afforded for secondary infection by micro-organisms.

Beet nematodes pierce through the epidermis of small rootlets to the true plerome elements at a time when the vessels are not fully differentiated. The rootlets contain differentiated rudiments of the phloem and xylem, frequently also isolated bundles of sieve tubes. In the portion of the cambium cells where the buccal portions of the worm begin to operate, the further formation of metaphloem and metaxylem is arrested; the parenchyma cells grow most, in part fuse together, and assume the pathological character of giant cells. Thus, vascular bundles that have already developed may be crushed and torn and the normal arrangement of the tissues be greatly disturbed by the thrust of the giant cells. This concerns chiefly the xylem. As already seen, the walls of single cells may be dissolved and cause the formation of the so-called syncytia. In every instance the plerome cells develop in an abnormal, pathological manner. The most marked effect of this is to cause a stoppage, or a fusion of the normal conductors of the rootlets. It has also been seen that the already differentiated vessels may be crushed and torn, that they come to lie between the thick walls of giant cells, whereby their

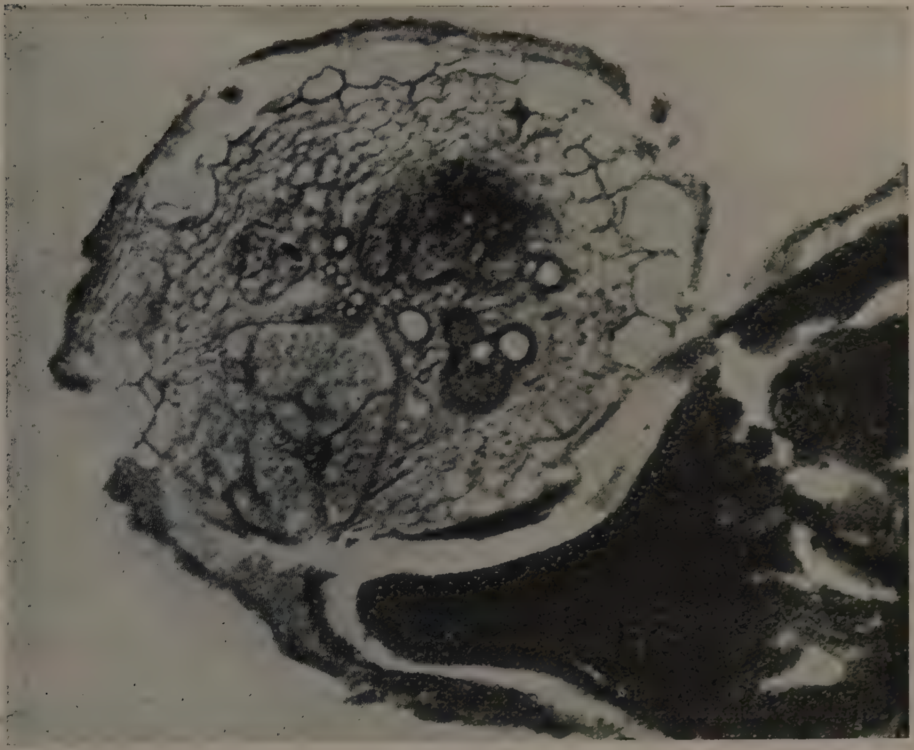


PLATE VII.

FIG. 1. CROSS SECTION THROUGH A LATERAL ROOTLET OF *BETA VULGARIS* WHICH HAS BEEN ATTACKED BY BEET NEMATODES.

The cortex is almost stripped off. There are several complexes of giant cells in the vascular bundles. (After Nemec.)

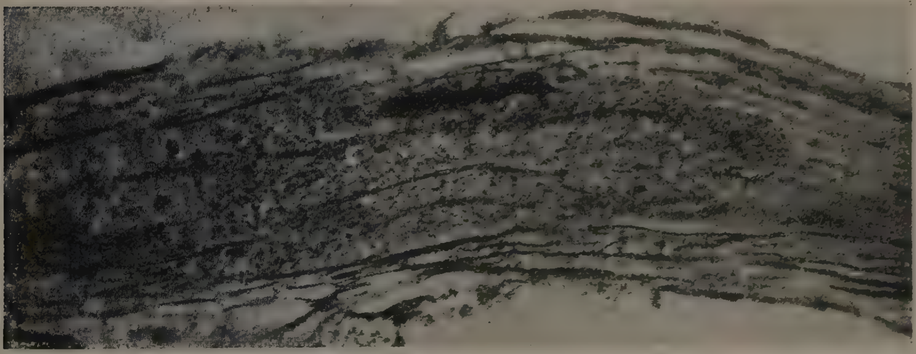


FIG. 2. LONGISECTION THROUGH A LATERAL ROOTLET IN THE TRACK OF A NEMATODE ATTACK.

The sheath-like giant cells, which include almost the entire length of the vascular bundles, may be observed. (After Nemec.)

functions are checked; besides this, the differentiation of the greater portion of the deuteroxylem in the infected zone is prevented. The whole complex of giant cells lies in the vascular bundle like a plug, interrupting or arresting the flow of plant foods, thus bringing about other sequences of nematode infection.

It is easy to see that in consequence of the plugging of the vessels of the rootlets scarcely any fluids can pass from the body of the beet to the vegetation points and the zone of growth; conversely, scarcely any soluble mineral foods can be absorbed by the root hairs. The plants, therefore, are almost as scantily furnished with water and mineral foods as though they possessed no rootlets. When the already formed rootlets have been thus plugged, new ones are developed to function in their place. These new rootlets in turn become infested, so the cycle is repeated until we have the dense mass of rootlets already mentioned. The diminution in the supply of water and foodstuffs interferes with photosynthesis and the formation of proteids.

This incessant stimulation to the development of new rootlets naturally still further exhausts the beets, which are already depleted of mineral foods. The yellowing and wilting of the leaves is one of the responses to this heavy drain upon the plant. This behavior of the foliage has generally been attributed to the lack of mineral foods in the soil. It is now apparent why the infested beets more readily wilt than healthy ones under the influence of heat and drouth.

To recapitulate: The plugging of the vascular bundles causes—

1. Regenerative formation of new rootlets;
2. Restriction of the growth of the individual rootlets;
3. Restriction of water transportation in the beet; and
4. Deficient absorption of mineral foods.

This deficiency of mineral solutions is further intensified by its incessant withdrawal by the worms, through the operation of which the giant cells are depleted of their contents and die at the time the pregnant females mature and fall off the rootlets.

In the dead syncytia, Němec found various bacteria and fungi. Syncytia invaded by fungi may exist which still contain a good deal of cytoplasm and nuclei. There are, then, numerous hyphæ in the vacuoles of the giant cells. They also extend among the intact portions of the bundles and especially in the phloem. Němec once noted hyphæ in a portion of a rootlet infested by immature females. The blackening and rotting of the crown may be attributed to secondary infections. It has been shown that the worm may infect the beet cells directly and cause the death of large groups of cells. The robust spear of *Heterodera schachtii,* which is used as a puncturing instrument, is only put into active operation when the worm seeks to force its way into the roots. As soon as it reaches the bundles, the spear itself is no longer needed, for the giant cells adjacent to the buccal opening remain quite uninjured. Since the cell membranes possess no pores, it is not to be assumed that the worm can nourish itself by simply absorbing the cell contents. Furthermore, threadlike mitochondrin is frequently to be found in the cells adjacent to the mouth parts of the worm (Němec, 1910) which, in places, brings about an intense metabolism, as for example, in nectaries. (Schniewind-Thies, 1897.)

It may be conceived that the worm, after it has pierced the endoderm and reached the elements of the vascular bundles, begins to secrete something which excites the cells to enlarge, to form much cytoplasm, to dissolve parts of the cell walls, and to secrete certain substances. These secretions are then sucked in as food by the nematode.

Either this continuous withdrawal of the secretion, or the persistent operation of a substance secreted by the worm, so acts that the giant cells function as nectaries as long as the worm continues to suck in the root. The worm then dies, the giant cells still further thicken their walls, become impoverished of cell contents, and die.

The bundles are but slightly thickened at the point of infection. No considerable cell proliferation and hypertrophy takes place, such as occurs in the galls produced by *Heterodera radicicola.* The giant cells originate chiefly through cell fusion.

EFFECT ON THE YIELD OF SUGAR BEETS.

The general effects of nematode injury have received much attention. As to the effect upon yield of root and foliage, Vanha and Stoklasa (1896) give the figures shown in Tables VIII which also shows the results of tests by Girard (1887).

TABLE VIII.—*Effect of the attacks of nematodes on the yield of sugar beets.*

AVERAGE WEIGHT PER BEET OF ROOT AND FOLIAGE AND PERCENTAGE OF SUGAR CONTENT, ACCORDING TO VANHA AND STOKLASA.

Specification.	Beets in 1892. Attacked.	Beets in 1892. Not infested.	Beets in 1893. Attacked.	Beets in 1893. Badly infested.	Beets in 1893. Not infested.
Leaves ....grams	104	225	158	58	310 210
Roots .... do.	276	804	310	184	618 530
Sugar content ....percent	10.05	13	11.35	8.4	14.65 14.9

AVERAGE WEIGHT AND SUGAR CONTENT OF BEETS, ACCORDING TO GIRARD.

Test.	Average weight (grams). Healthy.	Average weight (grams). Attacked.	Sugar content. W'g't per beet (grams). Healthy.	Sugar content. W'g't per beet (grams). Attacked.	Sugar content. Percentage of sugar. Healthy.	Sugar content. Percentage of sugar. Attacked.
1	357	228	46	27	13.04	12.02
2	625	300	76	33	12.24	11.17
3	500	285	61	29	12.37	10.11
4	450	200	54	17	11.96	8.76

Effect on the Chemical Composition of Sugar Beets.

Vanha (1893) also analyzed the leaves and roots of nematode infested beets, as shown in Table IX.

Susceptible Plants.

Although the number of plants thus far reported to be susceptible to the attacks of the beet nematode is much smaller than that of plants known to be attacked by the closely related rootknot nematode (*Heterodera radicicola*, Pl. V, fig. 3), it is already

TABLE IX.—*Chemical analyses of the dry matter of the leaves and roots of nematode-infested beets.*

Constituents, etc.		Leaves. Healthy.	Leaves. Diseased.	Roots. Healthy.	Roots. Diseased.
Average weights of the beets tested........	grams	363	104	703	276
Composition of dry substance:					
Nitrogen as proteids	Pct.	1.05	.53	.68	.42
As asparagin	do.	.29	.64	...	...
As asparagin (glutamin?)	do.	...	...	.29	.44
As various amid substances	do.	.97	.91	.38	.12
Precip. by phosphortungstic acid ...	do.	.43	.36	.19	.35
Cellulose	do.	25.88	36.99	...	...
Lecithin	do.	1.12	.52	.43	.32
Saccharose	do.	4.07	1.73	71.84	53.67
Hexose	do.	3.19	2.01	...	...
Oxalic acid soluble in water	do.	2.04	6.03	.07	.11
Oxalic acid insoluble in water	do.	3.92	.89	.04	.09
Pure ash	do.	22.14	10.07	5.04	3.02
Chemical composition of the pure ash:					
P_2O_5	Pct.	8.05	8.17	15.04	14.86
$Si\ O_2$	do.	17.31	16.03	2.03	2.16
SO_3	do.	9.14	10.6	12.00	13.02
K_2O	do.	17.71	13.04	40.91	30.13
Na_2O	do.	10.14	15.05	13.33	22.74
$Mg\ O$	do.	9.27	10.98	7.85	7.26
$Ca\ O$	do.	23.16	19.92	7.96	6.03
Fe_2O_3	do.	4.03	4.37	1.14	1.51

large. Additions are constantly being made to the list, which now includes a large proportion of the more important cultivated crops. The beet nematode is seen to be markedly polyphagous and appears to possess a considerable degree of adaptability. To such an extent is this the case that it is difficult to compile a sufficiently ample list of nonsusceptible crop plants for a reasonably long rotation system.

Ritzema Bos (1891) noted the occurrence of the beet nematode on 28 species of plants, belonging to 10 families; Vanha (1896) reported 40 species, and Marcinowski (1909) compiled a list embracing 60 species. Table X, which gives (1) the scientific name of the plant; (2) in parenthesis, the name under which it was reported if that differs from the name now used; (3) the common English name, if any; (4) the name of the person first reporting it on that host; (5) the date of observation. In this list, species now found wild in some portion at least of the beet zone of the United States are indicated by an asterisk (*); those marked with a dagger (†) are not found in this country; those not marked are in cultivation here.

According to Marcinowski (1909) the following are particularly susceptible: Cabbage, rape, beets (garden and sugar), rutabaga, mangolds, white and black mustard, garden cress, radish, cockle and spinach. Cabbage, beets and rape may be badly infested without showing symptoms of the disease, which may be accounted for by their extensive root systems. Oats in the same field may one year escape attack, but in another season they may become so badly infested that they must be cut while green.

According to the degree of certainty with which these plants are subject to attack by the sugar beet nematode, Kühn grouped them as follows:

1. Those especially and regularly subject to attack;
2. Those upon which nematodes only irregularly appear;
3. Plants which are only attacked by scattered individuals or colonies of nematodes; and
4. Weeds.

In the first group are to be placed, above all, beets of every kind, closely followed, in point of susceptibility to attack, by the *Brassica:* Cabbage, cauliflower, Brussels sprouts, rape, white and black mustard, garden cress, radish, kohl-rabi, etc.

In the second class, oats seem to be the most conspicuous example. Sometimes a crop of oats may be worse infested with nematodes than beets. Then again in a badly infested field they may remain entirely free from the pest.

In the group that is only occasionally attacked and but slightly affected are the legumes and clovers, most of which remain uninfested and are thus useful crops for infested fields. Kühn found but few nematodes on barley. He ascertained that barley may become infested, but never found many nematodes on barley roots. The pest is rather more frequently found on rye. According to Bolte, they do not often appear on potatoes, and this tuber is generally included in the German crop rotations. Chicory seems to be entirely resistant, even repellent, to nematodes.

In reference to the fourth group, weeds, it may be remarked that it is almost impossible to destroy the beet nematode by starvation, because it is impracticable, under ordinary conditions, to keep land entirely free from weeds of some kind. These serve as host plants for nematodes and enable the latter to survive.

PLANTS NOT ATTACKED BY THE BEET NEMATODE.

According to Hollrung (1890), the Solanaceæ, Papaveraceæ, Compositæ, and Umbelliferæ are not attacked by *Heterodera schachtii.*

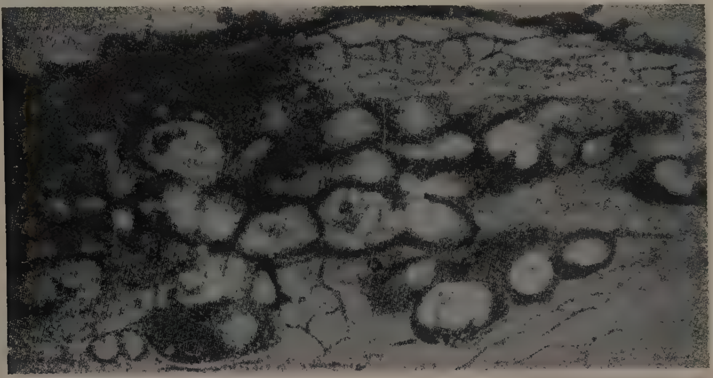
Vanha and Stoklasa (1896) reported that, according to the researches of Hollrung, the plants named in Table XI were exempt from nematode attack.

A comparison of the list in Table XI with the one compiled eleven years later by Marcinowski (1909) to show what plants were found to have become infested, shows that some important crop plants appear there which Vanha (1896) reported as being nonsusceptible. For example:

Compositæ—
  Helianthus annuus,
  Sonchus oleraceus.
Umbelliferæ—
  Apium graveolens,
  Pastinaca sativa.

Solanaceæ—
  Solanum tuberosum,
  Hyoscyamus niger.
Leguminoseæ—
  Trifolium repens,
  Trifolium incarnatum,
  Medicago sativa,
  Medicago lupulina,
  Vicia sativa,
  Pisum sativum,
  Phaseolus vulgaris.
Graminæ—
  Avena elatior,
  Phleum pratense,
  Sorghum saccharatum,
  Zea mays.
Also the following—
  Cannabis sativa,
  Humulus lupulus.
  Polygonum lapathifolium,
  Isatis tinctoria.

It is quite possible that many other plants have been infested without being observed, or that some have only escaped infestation owing to conditions external to the plant, unfavorable to the nematode.



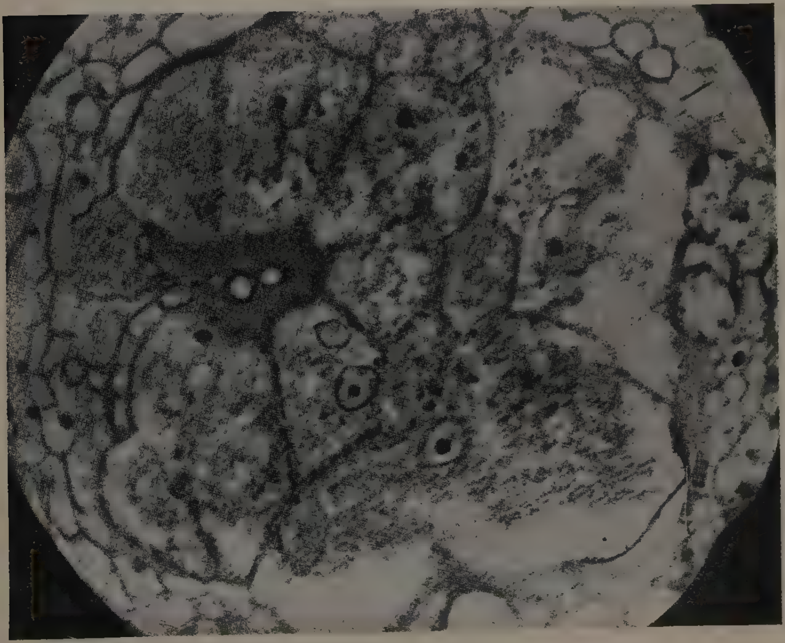


PLATE VIII.

FIG. 1. A GROUP OF GIANT CELLS WHICH SURROUND SEVERAL VESSELS OF A BEET ROOT.

The walls of the giant cells are greatly thickened where they come in contact with the vessels. (After Nemec.)

FIG. 2. CROSS SECTION THROUGH A PORTION OF A BEET ROOT WHERE IT HAS BEEN ATTACKED BY A BEET NEMATODE.

NONSUSCEPTIBLE PLANTS OF ECONOMIC IMPORTANCE.

From the foregoing lists it will be seen that but few of our important crop plants remain nonsusceptible to the attacks of the sugar-beet nematode. Probably still more are susceptible than have been observed or listed.

It requires little imagination to perceive that this foe is a formidable one. Small opportunity is afforded to make use of immune crops, because so few plants of importance to agriculture have thus far been observed to escape entirely the ravages of this pest.

Although European investigators have recommended and practiced a rotation system embracing five to seven years, with crops deemed nonsusceptible, it is by no means certain, in the light of the discoveries of Chatin (1887, 1888) and Fuchs (1911) on the preservation form of the beet nematode, the so-called brown cyst, that even a rotation of six years will suffice to rid the land entirely of this pest, though in practice such a rotation is reasonably satisfactory. Fuchs believes a period of eight years to be necessary, on account of the persistent viability of eggs protected by the brown cyst.

From the preceding list of plants believed to be nonsusceptible, those shown in Table XII may be considered of economic importance in the United States.

One of the most certain and persistent, though perhaps one of the slowest, methods of extending the ravages of this pest is through its own activity. Frank (1896) estimated the rate of progress of the larvæ of *Heterodera radicicola* at 3 centimeters a week. Its activities are likely to extend from May 1 to September 15, or later. According to the above rate of progression the larvæ would travel during the entire period but 75 centimeters, or about 30 inches. This is probably under the mark. It can hardly be questioned that the beet nematode is capable of making greater progress than this, even in heavier soils. Indeed, Vanha and Stoklasa (1896) state that it is able to migrate as much as 30 meters during a season, in search of food. On this point they state:

("Das Aushungern der Nematoden durch das Aussetzen des Zuckerrübenbaues und anderer von ihnen gesuchten Pflanzen, hat nicht den gewünschten Erfolg, weil im Boden immer noch genug Unkrauptflanzen vorhanden sind, an denen diese Schädlinge leicht ihre Existenzbedingungen finden können. Ueberdies haben diese Rübenschädlinge noch die Eigenschaft, dass sie herumwandern und nach bisher gemachten Beobachtungen *bis* 30 *m. weit übersiedeln können.*")

"The starvation of the nematodes by suspending the planting of sugar beets and other plants sought by them, has not had the desired result, as there are always enough weeds in the ground with which these larvæ can feed themselves. Moreover, these beet larvæ still possess the capacity of traveling and, according to previous observations, they are able to migrate as much as thirty meters."

The experiments of Fuchs (1911), herein described, substantiate the testimony of Vanha and Stoklasa.

Fuchs states that according to the experiments of Haberlandt, 1877, the larvæ of *Tylenchus tritici* can travel only 20 centimeters, and according to the more recent researches of Marcinowski, from 5 to 10 centimeters. Therefore, the results of the research of Fuchs were the more surprising in showing that the larvæ of *Heterodera schachtii* were able in two weeks to travel 3 meters, 20 centimeters in the presence of favorable moisture and temperature conditions.

Kühn (1881, 1886) demonstrated that the larvæ of one generation are able to travel 18 meters. But all his experiments were made in the field, where transportation by flowing water was not prevented. In the experiments of 1881 the transportation of cysts by means of plows was very probable. He himself said:

"Especially did they follow a southerly direction, probably because there the field is somewhat more retentive of moisture."

(Sie folgten dabei vorzugsweise der Richtung nach Süden, wahrscheinlich deshalb, der Acker etwas Feuchtigkeitshältiger ist. * * *)

This leaves one to conclude that a wandering in the direction of trickling rain water was observed. It is generally known that water, both in small quantities in fields, and in large ones in river and stream, is a great and, therefore, dangerous means of transportation. These disturbing factors, then, must be removed, should we attempt to determine to what distance the larvæ can travel. Equally, transportation by methods of cultivation should be avoided.

Wooden boxes 20 centimeters deep and

TABLE X.—*Plants susceptible to attack by the sugar-beet nematode.*

[1] The nomenclature followed in these lists is that used by the systematic botanists of the Bureau of Plant Industry. The list was submitted to the office of Taxonomic Investigations of that Bureau, where it was revised by Mr. P. L. Ricker.

Scientific name.	Common name.	Observed by.
**Agropyrum repens (Triticum repens)*	Couch-grass	Tarnani, 1898.
**Agrostemma githago*	Corn cockle	Kühn, 1881.
**Alsine media (Stellaria media)*	Chickweed	Hollrung, 1890.
**Anchusa officinalis (A. arvensis)*	Ox tongue	Liebenberg (according to Kühn, 1881).
Apium graveolens	Celery	Frank, 1896.
**Arrhenatherum elatius*	Tall meadow oat grass.	Hollrung, 1890.
**Atriplex hortensis*	Garden orach	Kühn, 1881.
**Avena sativa*	Oats	Kühn, 1874.
**Beta vulgaris*	Beets	Schmidt, 1871.
**Brassica sp:*		
B. arvensis (Sinapis arvensis)	Charlock	Kühn, 1881.
B. campestris	Rutabaga	
B. juncea	Chinese mustard	
B. napus	Rape	
B. nigra (Sinapis nigra)	Mustard	
B. oleracea botrytis	Cauliflower, broccoli.	
B. oleracea capitata	Cabbage	
B. oleracea viridis	Kale, collard	
B. pekinensis	Chinese cabbage	
B. rapa	Turnip	
B. alba (Sinapis alba)	White mustard	
**Camelina sativa*	False flax	
**Cannabis sativa*	Hemp	Hollrung, 1890.
**Chætochloa viridis (Setaria viridis)*	Green foxtail	Hollrung, 1890.
**Chenopodium album*	Pigweed	Kühn, 1881.
**Chenopodium glaucum*		Hollrung, 1890.
**Chenopodium polyspermum*	Allseed	Tarnani, 1898.
**Dianthus sp. (4 species introduced)*	Pink	Chatin, 1891.
**Erodium cicutarium*		Liebenberg (according to Kühn, 1881).
**Helianthus annuus*	Sunflower	Schmidt, 1872.
Holcus saccharatus (Sorghum saccharatum)	Sorghum	Hollrung, 1890.
**Hordeum distichon*	Six-rowed barley	Kühn, 1874.
**Hordeum vulgare*	Two-rowed barley	Hollrung, 1890.
**Humulus lupulus*	Hops	Percival, 1895.
**Hyoscyamus niger*	Black henbane	Vanha and Stoklasa, 1896.
Isatis tinctoria	Dyer's woad	Hollrung, 1890.
**Lamium amplexicaule*	Dead nettle, henbit	Hollrung, 1890.
†*Lathyrus cicera*	Lesser chick-pea	Kühn, 1881.
**Lathyrus odoratus*	Sweet pea	Frank, 1896.
Lentilla lens (Ervum lens)	Lentil	Hollrung, 1890.
**Lepidium sativum*	Garden peppergrass	Kühn, 1881.
†*Lupinus luteus*	Yellow lupine	Frank, 1896.
**Lycopsis arvensis*	Wild bugloss	Vanha and Stoklasa, 1896.
**Medicago lupulina*	Yellow trefoil	Tarnani, 1898.
**Medicago sativa*	Alfalfa, lucern	Hollrung, 1898.
**Pastinaca sativa*	Parsnip	Hollrung, 1890.
**Phaseolus vulgaris (P. nanus)*	Dwarf pea-bean	Hollrung, 1890.
Phaseolus vulgaris	Kidney bean	Frank, 1896.
**Phleum pratense*	Timothy	Hollrung, 1890.
Pisum sativum	Garden pea	Liebscher, 1890.
**Poa annua*	Annual meadow grass.	Liebenberg (according to Kühn, 1881.)
**Polygonum lapathifolium*	Pale persicaria	
**Reseda lutea*	Dyer's rocket	Gain, 1894 (according to Houard, 1908).
**Rhaphanus raphanistrum*	Wild radish	Kühn, 1881.
**Rhaphanus sativus*	Radish	Schmidt, 1872.
**Secale cereale*	Rye	Kühn, 1881.
**Sinapis* (See *Brassica* sp.)		
**Solanum nigrum*	Black nightshade	Vanha and Stoklasa, 1896.

**Solanum tuberosum*	Potato	Bolte (according to Kühn, 1881).
**Sonchus asper (S. oleraceus)*	Sow thistle	Tarnani, 1898.
Spinacia oleracea	Spinach	Schmidt, 1872.
**Taraxacum officinale*	Dandelion	Vanha and Stoklasa, 1896.
**Trifolium incarnatum*	Crimson clover	Hollrung, 1890.
**Trifolium repens*	White clover	Hollrung, 1890.
**Trificum æstivum (T. vulgare)*	Wheat	Kühn, 1874.
**Vicia sp.* (also in cultivation)	Vetch	Liebscher, 1890.
Zea mays	Corn	Hollrung, 1890.

[1] According to L. P. Byars (correspondence with the author, January, 1913) the sugar-beet nematode has been observed in California on the curled dock (*Rumex crispus*) and red pigweed (*Amaranthus retroflexus*).

TABLE XI.—*Plants exempt from beet-nematode attack, according to the researches of Hollrung.*[1]

According to a later list by Marcinowski, plants marked with a star (*) are susceptible.

	Scientific Name.	Common Name.
Asteraceæ:		
1.	*Cichorium intybus*	Chicory.
2.	*Lactuca sativa*	Lettuce.
*3.	*Helianthus annuus*	Sunflower.
4.	*Helianthus tuberosus*	Jerusalem artichoke.
5.	*Artemisia dracunculus*	Biting dragon.
6.	*Matricaria chamomilla*	Wild camomile.
7.	*Calendula officinalis*	Garden marigold.
8.	*Carduus crispus acanthoides (C. acanthoides)*	Welted thistle.
9.	*Mariana lactea (Silybum marianum)*	Milk thistle.
10.	*Carthamus tinctorius*	Safflower.
11.	*Cnicus benedictus*	Blessed thistle.
12.	*Centaurea jacea*	Knapweed or centaury.
13.	*Bellis perennis*	English daisy.
14.	*Tragapogon porrifolius*	Oyster plant.
15.	*Scorzonera hispanica*	Winter asparagus.
16.	*Madia sativa*	Tarweed.
17.	*Dipsacus fullonum*	Fuller's teasel.
*18.	*Sonchus asper (S. oleraceus)*	Sow thistle.
19.	*Senecio vulgaris*	Groundsel.
Aniaceæ:		
*20.	*Apium graveolens*	Celery.
21.	*Carum petroselinum (Petroselinum sativum)*	Parsley.
22.	*Carum carvi*	Caraway.
23.	*Pimpinella anisum*	Anise.
24.	*Anethum graveolens*	Dill.
*25.	*Pastinaca sativa*	Parsnip.
26.	*Heracleum sphondylium*	European cow parsnip.
27.	*Daucus carota*	Carrot.
28.	*Anthriscus cerefolium*	Garden chervil.
29.	*Chaerophyllum bulbosum*	Parsnip chervil.
30.	*Coriandrum sativum*	Coriander.
Solanaceæ:		
*31.	*Solanum tuberosum*	Potato.
32.	*Nicotiana tabacum*	Tobacco.
33.	*Capsicum annuum*	Red or cayenne pepper.
34.	*Datura stramonium*	Jimson weed.
*35.	*Hyoscyamus niger*	Black henbane.
Papaveraceæ:		
36.	*Papaver somniferum*	Poppy.
Fabaceæ:		
37.	*Trifolium pratense*	Red clover.
*38.	*Trifolium repens*	White clover.
39.	*Trifolium hybridum*	Alsike clover.
*40.	*Trifolium incarnatum*	Crimson clover.
41.	*Trifolium alexandrinum*	Egyptian clover.
*42.	*Medicago sativa*	Alfalfa, lucern.
43.	*Medicago sativa varia (M. media)*	Sand lucern.
44.	*Medicago falcata*	Sickle-podded clover.
*45.	*Medicago lupulina*	Yellow trefoil.
46.	*Trigonella foenumgraecum*	Fenugreek.

47.	*Anthyllis vulneraria*	Kidney vetch.
48.	*Melilotus alba*	Sweet white clover.
49.	*Melilotus officinalis*	Yellow clover.
50.	*Lotus corniculatus*	Bird's-foot trefoil.
51.	*Ornithopus sativus*	Seratella.
52.	*Onobrychis vulgaris (O. sativa)*	Sainfoin.
53.	*Onobrychis petraea (Hedysarum petraeum)*	
54.	*Cicer arietinum*	Chick-pea.
55.	*Lens lentilla (L. esculenta)*	Lentil.
56.	*Vivia monanthos (Ervum monanthos)*	
*57.	*Vicia sativa*	Common vetch.
58.	*Vicia faba*	Horse bean.
59.	*Lathyrus clymenum*	Spanish pea.
60.	*Lathyrus sativus*	Bitter vetch.
61.	*Lathyrus latifolius*	Everlasting pea.
62.	*Lathyrus ochrus*	Yellow-flowered pea.
*63.	*Pisum sativum*	Garden pea.
*64.	*Phaseolus vulgaris*	Kidney bean.
65.	*Lupinus augustifolius*	Blue flowered lupine.
*66.	*Lupinus luteus*	Yellow lupine.
67.	*Lupinus albus*	White lupine.
68.	*Lupinus perennis*	Old maid's bonnet.

Poaceæ:

69.	*Lolium perenne*	Perennial rye-grass.
70.	*Lolium multiflorum (L. italicum)*	Italian rye-grass.
71.	*Lolium temulentum*	Darnel.
*72.	*Hordeum vulgare*	Two-rowed barley.
73.	*Hordeum bulbosum*	
74.	*Elymus arenarius*	Upright sea-lyme grass.
75.	*Triticum turgidum*	Duck-bill wheat.
76.	*Triticum polonicum*	Wild-goose wheat.
77.	*Triticum spelta*	Spelt wheat.
78.	*Triticum monococcum*	One-grained wheat or St. Peter's corn.
79.	*Bromus secalinus*	Chess.
80.	*Bromus mollis*	Soft brome-grass.
81.	*Bromus arvensis*	Corn brome-grass.
82.	*Bromus erectus*	Upright brome-grass.
83.	*Festuca elatior (F. pratensis)*	Tall meadow fescue.
84.	*Festuca gigantea*	Giant fescue grass.
85.	*Festuca ovina*	Sheep's fescue.
86.	*Cynosurus oristatus*	Crested dog's-tail grass.
87.	*Dactylis glomerata*	Orchard grass.
88.	*Poa pratensis*	Kentucky bluegrass.
89.	*Poa compressa*	Canada bluegrass.
90.	*Melica ciliata*	Ciliated melic grass.
91.	*Avena fatua*	Sand oats.
92.	*Trisetum flavescens (Avena flavescens)*	Yellow oat-grass.
*93.	*Arrhenatherum elatius (A. elatior)*	Tall oat-grass.
94.	*Hotholcus lanatus (Holcus lanatus)*	Velvet grass.
95.	*Deschampsia caespitosa (Aira caespitosa)*	Tufted hair-grass.
96.	*Deschampsia flexuosa (Aira flexuosa)*	Hair-grass.
97.	*Koeleria cristata*	Prairie grass.
98.	*Agrostis alba*	Herd's-grass, redtop.
99.	*Agrostis alba vulgaris (A. vulgaris)*	Rhode Island bent-grass.
100.	*Capriola dactylon (Cynodon dactylon)*	Bermuda grass.
*101.	*Phleum pratense*	Timothy.
102.	*Alopecurus pratense*	Meadow foxtail.
103.	*Anthoxanthum odoratum*	Sweet vernal grass.
104.	*Phalaris canariensis*	Canary grass.
105.	*Chaetochloa italica (Setaria italica)*	Italian millet.
106.	*Panicum miliaceum*	Millet.
107.	*Syntherisma sanguinale (Panicum sanguinale)*	Crab-grass.
108.	*Andropogon ischaemum*	Woolly andropogon.
*109.	*Sorghum saccharatum*	Sorghum or Chinese sugar cane.
*110.	*Zea mays*	Corn.

Outside of the above-named families, the following are not attacked by the beet nematode:

111.	*Linum usitatissimum*	Flax.

*112. *Cannabis sativa*	Hemp.
*113. *Humulus lupulus*	Hops.
114. *Radicula armoracia (Cochlearia armoracia)*	Horse-radish.
115. *Fagopyrum vulgare (Polygonum fagopyrum)*	Buckwheat.
116. *Fagopyrum tartaricum (Polygonum tartaricum)*	Tartary buckwheat.
117. *Polygonum sieboldi*	
*118. *Polygonum lapathifolium*	Pale persicaria.
119. *Convolvulus*	Bindweed.
120. *Allium cepa*	Onion.
121. *Allium ascalonicum*	Shallot.
122. *Allium schoenoprassum*	Chives.
123. *Allium porrum*	Leek.
124. *Asparagus officinalis*	Asparagus.
125. *Cucumis sativus*	Cucumber.
126. *Cucurbita pepo*	Pumpkin.
127. *Fragaria vesca*	Strawberry.
128. *Rubus idaeus*	European raspberry.
129. *Ribes reclinatum (R. grossularia)*	Gooseberry.
130. *Hedera helix*	English ivy.
*131. *Isatis tinctoria*	Dyer's woad.
132. *Viola odorata*	English violet.
133. *Dianthus carthusianorum*	Carthusian pink.
134. *Spergula arvensis*	Spurry.
135. *Sanguisorba minor (Poterium sanguisorba)*	Burnet.
136. *Portulaca oleracea*	Purslane.
137. *Oenothera biennis*	Evening primrose.
138. *Saponaria officinalis*	Bouncing Bet.
139. *Nigella sativa*	Black cumin.
140. *Rumex acetosa*	Sheep sorrel.
141. *Rumex crispus*[1]	Curled dock.
142. *Rumex glomeratus*	Clustered dock.
143. *Atriplex hastatum*	Lamb's-quarters.
144. *Euphorbia* sp.	Spurge.
145. *Fumaria officinalis*	Fumitory.
146. *Lychnis alba (Melandrium album)*	Bachelor's-button.
147. *Antirrhinum majus*	Snapdragon.
148. *Borago officinalis*	Borage.
149. *Convolvulus tricolor*	Three-colored bindweed.
150. *Valerianella olitoria*	Corn sald.
151. *Plantago lanceolata*	English plantain.
152. *Tropaeolum majus*	Nasturtium.
153. *Althaea rosea*	Hollyhock.
154. *Mentha crispa*	Curled mint.
155. *Salvia officinalis*	Scarlet sage.
156. *Salvia pratensis*	White sage.
157. *Thymus serpyllum*	Wild thyme.
158. *Satureja hortensis*	Summer savory.
159. *Amaracus vulgare (Origanum majorana)*	Sweet marjorum.
160. *Lamium purpureum*	Red dead nettle.
161. *Sesamum orientale*	Sesame.
162. *Arenaria serpyllifolia*	Sandweed.
163. *Aesculus hippocastanum*	Horse-chestnut.
164. *Prunus domestica*	Greengage plum.
165. *Prunus mahaleb*	Mahaleb cherry.
166. *Amygdalus communis (Pyrus communis)*	Almond.
167. *Malus sylvestris*	Apple.

[1] According to Byars, this plant has been found attacked by the beet nematode in California, (by G. F. Scott, near Spreckels, Cal., 1911).

TABLE XII.—*Nonsusceptible plants of major or minor importance.*

A.—PLANTS OF MAJOR IMPORTANCE.

Scientific Name.	Common Name.
Agrostis alba	Herd's-grass, redtop.
Agrostis vulgaris	Rhode Island bent-grass.
Dactylis glomerata	Orchard grass.
Festuca pratensis	Tall meadow grass.
Linum usitatissimum	Flax.
Nicotiana tabacum	Tobacco.
Prunus domestica	Greengage plum.
Triticum spelta	Spelt wheat.

B.—PLANTS OF MINOR IMPORTANCE.

Allium cepa	Onion.
Asparagus officinalis	Asparagus.
Capsicum annuum	Red or cayenne pepper.
Carum petroselinum	Parsley.
Cichorium intybus	Chicory.
Cucumis sativus	Cucumber.
Cucurbita pepo	Pumpkin.
Daucus carota	Carrot.
Fragaria vesca	Strawberry.
Helianthus tuberosus	Jerusalem artichoke.
Lactuca sativa	Lettuce.
Tragapogon porrifolius	Oyster plant.

C.—PLANTS OF MAJOR OR MINOR IMPORTANCE ACCORDING TO LOCALITY.[1]

Chaelochloa italica	Italian millet.
Melilotus alba	White sweet clover.

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[1] The potato, which in Europe is found to be but little subject to nematode infestation and is therefore generally included in rotation series, might be added to list C.

30 centimeters wide and of various lengths were filled with soil which, as a precaution, had been placed, in part, in a *Schimmelbusch* sterilizer at 100° C. and, in part, it was heated to 80 or 90° C. over an open fire, therefore, absolutely freed of nematodes. As soon as this soil had settled into a normal condition, partly by sprinkling, and partly by compacting, one end of each box was filled in with nematode-infested soil for about 10 centimeters of its length and the entire depth. This soil was then closely compressed to bring it thoroughly in contact with the sterile soil. The boxes were then inclined at a slope of about 1 in 20, with the infested soil at the lower end, thus avoiding the chance of larvæ being carried from infested to sterile soil by water that might be sprinkled on the surface.

On March 7 two boxes were sown with *Sinapis alba*. This was done thickly in box No. 1, especially in the nematode-infested soil, so that an abundance of host plants should be provided. In box No. 2 no seed was sown in the infested soil, but in the sterile soil two rows were sown lengthwise, so that here the host plants should not be very plentiful.

On March 12 the washing tests hitherto described showed that larvæ had begun to emerge and travel.

On April 7 the month-old plants were examined, showing in both boxes that larvæ had penetrated only 7 centimeters into the sterile soil. No difference could be observed whether few or many host plants were available. They had never developed beyond the first larval stage. Fuchs did not find a single flask form. That they had traveled so short a distance is to be explained by the prevailing low temperature. When all plants had been removed, together with adhering soil, the boxes were again filled with healthy soil, and on April 8 sowed with mustard. In box No. 1 the rows ran crosswise about 10 centimeters apart. In box No. 2 there were four lengthwise rows through the entire box, and three cross rows in box No. 3, set from 20 to 30 centimeters apart.

On April 30 (after three weeks) the plants in box No. 1 were examined and larvae were found in cross rows 120 centimeters from infested soil. In box No. 2, they had penetrated 132 centimeters, though, to be sure, they were quite scattered in the last 50 centimeters. Nevertheless Fuchs found five larvae in the rootlets of one plant 128 centimeters distant. A like result was obtained in box No. 3, where some larvæ were found in a cross row 120 centimeters from the infested soil. The plants that grew near the end of the box, 30 centimeters farther away, were free.

Since from these surprising results it was found that a box of 150 centimeters was not long enough, the experiment was then tried in a box 4.50 meters long. A box of this size was filled on June 4 with soil that had been heated to 100° C. and, at the lower end, for a distance of 10 centimeters, with soil containing cysts. On June 18 two rows of *Sinapis alba* were sowed lengthwise in it.

On July 4 Fuchs examined them and found in the rootlets of the young plants, at the infested end, larvæ that had reached the flask form. Flask forms were also found 10 centimeters farther, and as far away as 50 centimeters numerous young larvæ were found. At a distance of 70 centimeters an average of one larvæ to five plants was found; at 80 centimeters from infested soil, one larva in about four roots; beyond 80 centimeters none were found. The plants 80 centimeters distant were now left, therefore, at a distance as great as he had found larvæ. All the plants intervening between these and the infested soil were destroyed, and the space was filled in with soil that had been heated to 100° C.

On July 16 white mustard was again sown, the plants being examined on July 30, whereby it was shown that the nematodes had traveled 4 meters, equaling a distance of 3.20 meters for one generation in two weeks. It is true that but few larvæ traveled so far, only one larva being found among eight plants, as against two larvæ to one root on plants 3.40 meters distant, corresponding to a journey of 2.60 meters. At a distance of 2.80 meters, equaling a journey of 2 meters, about four embryos to a root were found. As a control for these surprising results Fuchs repeated the experiment, emptied and scorched the dry boxes with a Bunsen burner to sterilize them, filled them with nematode-free soil, and again set them at a similar slope, putting in infested soil in the same way.

On August 17, two rows of white mustard were sown. On August 31 Fuchs examined the plants and found nematodes 2.20 meters distant. He allowed the infested plants to remain. The others were removed and a fresh sowing made. By September 17 the plants at the end of the box were attacked, corresponding to 4.4 meters from the infested soil, and a journey of 2.30 meters in one generation. He believed that had the boxes been longer the larvæ would have traveled farther.

Fuchs has therefore absolutely demonstrated that young larvæ of *Heterodera schachtii* are able to travel a remarkable distance in soil. It is also shown that this ability is correlated with the temperature of the environment. The distance traveled is the greater the higher the temperature rises. It would appear that the average temperature of the midsummer of the hot districts of Europe is the optimum for the vital activities of the larvæ. Conversely, with falling temperatures the vital expressions are duller, their movements slower, and their journey shorter. It also appears that the distance they can travel depends somewhat on the character of the soil—the condition, porosity, and mechanical constitution of the ground. In order to determine this, two boxes were taken and filled with typical "Türkenschwanzsand," very open, the other with heavier loam (Table VI). The latter was also pressed as much as possible. Each was filled at one end with nematode-infested soil. On August 3 a row of white mustard was sown lengthwise in each box. On August 19 both boxes were examined. In the sand the larvæ had infested all the plants in about equal degree, the whole length of the box, viz., 1.50 meters. An average of four larvæ were found on each root. In the loam they had traveled only 1.35 meters, but plants over 50 centimeters distant were only irregularly and feebly attacked. Beyond 1 meter, about 1.5 larvæ to the root were found.

It is seen, then, that the distance traveled depends considerably on the kind of soil. It is a fact that the larvæ of *Heterodera schachtii* are able to travel 3 to 4 meters in search of food, so that in one year, by its own activity, with five to six generations, *Heterodera schachtii* may penetrate 15 to 24 meters (49.2 to 78.75 feet) and may even travel against running water by its own powers.

In nature the matter is quite otherwise, and far more favorable to the spread of the larvæ, because there running water becomes a factor of transportation not to be underestimated.

The present writer is of the opinion that Fuchs overestimates the total distance the larvæ of *Heterodera schachtii* are capable of traveling in one year, since, from his own showing, the earlier generations do not travel nearly so far as those arising during the warm season, nor are those generations arising late in the summer or fall capable of such extended travels. Probably one-half to two-thirds of Fuchs' estimate would be more nearly correct, or about 30 to 45 feet in one season.

BY TRANSPORTATION OF INFESTED SOIL.

But there are many other effective methods of spreading the pest, both more rapidly and widely. Soil borne on the shoes of laborers and others traversing fields, on the hoofs of horses and other farm stock, on implements, and on wagon wheels; all these would be fruitful means of conveying the pest from infested to clean fields. Soil shaken from infested beets into wagons in which beets are hauled to the factory might be scattered in clean fields; beet trash from the factory, or mud from the settling pond, spread on fields as fertilizers, may become prolific sources of infestation.

OTHER AGENTS.

Heavy rains also spread the pest from higher to lower ground. In irrigated portions of the United States, nematodes may be spread very extensively by means of irrigation water. According to Vanha and Stoklasa, there is little to fear that it may be spread by wind, because, as we are given to understand, it can not withstand drying; thus, under conditions where the soil might be carried by wind, the nematode could not survive. However true this may be of the free-living forms, it does not follow that the brown cyst may not be thus transported.

Since many other crops are susceptible to the attacks of this worm, there is no reason why it may not be spread by methods incidental to the handling of such crops.

It was long thought that sheep and other farm stock could spread the nematode by means of their droppings. One investigator declared that he had discovered innumerable live nematodes in the dung of sheep. If he did, they were probably intestinal worms. Chatin (1890) fed sheep on badly infested beets for several weeks. Careful examinations of their dejecta revealed no live, beet nematodes, or nematodes of any kind, although the debris of such worms was found in abundance.

CONDITIONS FAVORING THE BEET NEMATODE.

Soil.—It would appear from European experience that cultural conditions in general favor the perpetuation and spread of the beet nematode. As the result of an experiment to determine whether shallow or deep winter plowing would increase the yield of beets, Müller (1911) concluded that deep plowing was more unfavorable to the beets. The beet nematode, unlike the root-knot nematode, is sufficiently robust to thrive in almost any kind of soil, light or heavy. The known host plants are so numerous and widespread, including, as they do, some of the commonest weeds of Europe and, through introduction, of this country, as well as many important cultivated plants, that the worm is afforded ample opportunity to subsist apart from the presence of sugar beets.

Temperature.—Although the eggs and larvæ may be killed by slight frosts, the brown-cyst stage is able to withstand the rigors of winter. However, there seems to be little doubt that larvæ seek the deeper soil on the approach of winter, while still others gain entrance to root tissues, where they may survive until the following spring.

On the other hand, the summer temperature of the soil is highly favorable to the active and rapid development of this nematode. The eggs succumb to a temperature of 25° C. and the free-living adults are destroyed by a temperature of 35° C. The optimum range of temperature for the larvæ seems to lie between 15° and 25° C. Fuchs (1911) states that a soil temperature of 63° C. is sufficient to kill the contents of the brown cysts.

From this it would appear that in many states the cold of winter is severe enough to penetrate sufficiently deep to destroy all except the eggs and larvæ protected by the brown cysts. In this respect it would appear to differ from the root-knot nematode, according to Bessey (1911), who reported that he "saw it abundant on ginseng in a slat shed at Menominee, Mich., where the soil, a year or so before, froze to a depth of more than 3 feet, and where, outside the shed, water pipes 6 feet below the surface were frozen. In spite of this cold the nematode injuries were bad the next year. In York, Nebr., where the temperature goes below zero every year, and sometimes reaches nearly, or quite, to —30° F., this nematode survived the winter out of doors without protection."

The same writer continues:

> "His experiments show that the nematodes are more active in midsummer, and that infection occurs more freely the warmer the weather, except where lack of rain permits the soil to dry out, in which case both plants and nematodes cease to thrive."

Störmer and Merganthaler state that the unusual drought of 1911 (in Germany) seemed to be very favorable to the beet nematode, and the heat stimulating to its development, but these conditions were, at the same time, unfavorable to the beets.

Moisture.—The degree of moisture usually retained in cultivated soils is highly favorable to the activities of nematodes.

Weeds.—The rootlets of rank growths of weeds, many of them favorite host plants of both root-knot and sugar beet nematodes, so commonly left on roadsides, margins of fields, and along irrigation ditches, as well, probably, as the weeds that spring up in fields after the harvesting of crops, afford splendid holdover places.

Susceptible Crops.—The repeated cultivation of sugar beets and other crops susceptible to nematode attack is also most favorable to the persistence and increase of the pest.

Prolific Character.—The sugar-beet nematode is known to be very prolific. From five to seven generations may come into existence in a single season. Suppose each female to bring forth only 100 young, it would mean the theoretical possibility of a progeny of 31,887,755,100 individuals in six generations, or the astounding number of 22,781,000,000,000 if each female produced the probable average of 300 young. (Vanha and Stoklasa, 1896.)

Absence of Enemies.—Wolff states that the beet nematode is not known to have any insect or other enemy, and to a large extent it is protected from climatic dangers by the soil.

Control of the Beet Nematode in Isolated Spots.

WITH LIVE STEAM.

Since the control of the beet nematode is essentially a field problem, only passing mention will be made of methods whose application is practicable only on a small scale, as for example, in the greenhouse or on small garden plats. Among these are the use of live steam under pressure (Bessey, 1911).

WITH CHEMICALS.

In Europe innumerable attempts have been made to check or destroy the beet nematode by means of chemicals applied directly to the soil, but while some of the methods have proved successful on the small scale, to exterminate the worms from small isolated areas, all have had to be discarded, when applied to general field conditions, as being either inefficacious or too costly.

Carbon Disulphid.—Among the more important agents and methods might be mentioned the application of carbon disulphid. The manner of applying this is to bore holes about 8 inches deep and 20 inches apart in the infested areas, then to pour 100 cubic centimeters of carbon disulphid in each hole (Kühn, 1871 to 1905), filling up the holes with soil to prevent undue loss by evaporation of the chemical. Spiegler (1907) states that in 1894 he was able to destroy the nematodes only by the application of considerable quantities of this substance. Bessey, in 1907, found that in deep, sandy soil not all nematodes were killed by the application of 2 ounces of carbon disulphid per yard. In his experiments he made holes about 1 foot deep with a dibble, eight or nine to the square yard, using about a teaspoonful in each hole. To use much of this substance near growing plants would be dangerous to them. Spiegler also tried Hollrung's method of application. In a plat of infested beets, holes about 8 inches deep were made, 20 inches apart in the row, 100 cubic centimeters of carbon disulphid was poured in into each hole, the holes were then immediately filled with soil and trodden. Each row so treated was alternated with an untreated check row. On noting the result of the experiment, Spiegler exclaimed:

> "To my horror I found the nematodes everywhere. I have concluded that a small quantity of carbon disulphid does not injure the worms, and a large quantity is too costly."

Gas Water and Other Chemicals.—Gas water, gas lime, quicklime, calcium carbid, and other chemicals have been thoroughly tested. Some of these are efficacious when used in large quantities, as already stated, and are of value in operating on small areas, but all are impracticable, inefficacious, or too costly for field work. Most of them are injurious to plants.

FIELD CONTROL.

Fertilizers.—Since infested beets manifest symptoms resembling those due to a lack of certain mineral foods, notably potassium, it was long thought that heavy applications of commercial fertilizers, rich in that element, might have beneficial results. Much work was done in that direction. This was carried so far that in many instances fields were over-fertilized, to the detriment of beets and other crops. Wilfarth and Wimmer (1903) have shown that nematodes abstract in nearlv equal degree all the important plant foods from the beet. Therefore, should only a small quantity of potassium be present in the soil, the beets will soon show signs of potassium starvation and exhibit the typical symptoms —small weight, low sugar content, high percentage of foliage, as well as the appearance of yellow and brown spots on the leaves and a general curling of the surviving foliage.

Schander believes that in individual instances the liberal application of fertilizers, especially potassium salts, will diminish the injury due to nematode attack, but he does not by any means regard such treatment as suitable for universal application.

An extensive series of experiments has been carried on at the Bernburg Experiment Station[1] to test the efficacy of the application of various fertilizers and plant foods as a means of at least reducing the ill effects of nematode attacks. In some cases a marked improvement in yield resulted, but no diminution in the number of worms.

Uzel (1911) recommends that young, badly infested beets be plowed out and left on the surface of the ground, it being expected that, as the beets dry, large numbers of the nematodes would be destroyed.

Should there be an abundance of potassium in the soil the sugar percentage may not be reduced, but, despite the addition of fertilizers, the total yield will not be augmented. The plants may for a time appear to gain headway against the nematodes, or the latter to be destroyed in part. The partial destruction of the pest is only apparent, as they remain uninjured, but the plants are temporarily stimulated. Notwithstanding this evidence, it is still held by some that the symptoms of beet weariness simply accompany nematode attacks, but are not caused by the parasite, or at least, only partially so. It is claimed that the disease arises in a manner analogous to a similar wilted or "weary" appearance in certain other plants, in which nematodes certainly play no part. It is noted in such plants after the same crop has repeatedly been grown on the same land. It appears to be due especially to an impoverishment of the soil in certain materials quite indispensably necessary to the plant, and to an increase of injurious substances which stimulate the development of flora and fauna injurious to the roots. The latter part of this contention apparently has some support in the fact that beet weariness is generally worst in fields that have too repeatedly been cropped with beets.

Parasitic Fungi.—Attempts have also been made to destroy the beet nematode by means of parasitic fungi, but on account of the great expense entailed by such a method, and the doubtful character of the results, it merits no further consideration.

Flooding.—Flooding is not recommended as a practical method of destroying nematodes. Stift claims that it is of no value for this purpose; rather would it seem to be positively harmful, since the chances would ordinarily be greater for the spread of the worm than for its destruction.

Drying.—It has been shown that the free-living forms, at any rate, of the beet nematode are very susceptible to drying. Exposure to wind and sunshine quickly kills them; therefore, unless they penetrate to the deeper and moister soil, they would be destroyed in the surface layer. Thus it might be practicable to reduce their number, especially in the semiarid belt, by repeated deep stirring of the soil during the summer. This would probably not avail against the cyst.

Fallow.—The evidence goes to show that the beet nematode can endure starvation for a long period, certainly more than a year. It is much more certain, however, that it survives in the preservation form known as the brown cyst, than that free-living forms can long exist without food. Any fallow system designed to exterminate beet nematodes would have to take this preservation form into account. We have seen that the brown cysts can preserve their contents in a viable condition as long as five years. To be sure, a fallow of even two or three years would cause the destruction of most of the nematodes in the soil, if the ground were meantime kept absolutely free from weeds, or plants of any kind. This would be additionally effective if the ground were also stirred during the hot months. Of course, this method is open to the objection that the land remains unproductive, but this would be far better than to continue to get scanty yields from infested land. In some regions, too, bare land would be subject to washing by heavy rains, or, in other localities, light soils might be shifted by strong winds.

Alkaline Solutions.—In Europe, a prolific means of infestation has been through the application of slime from the sugar factory settling ponds as fertilizer to hitherto uninfested land. While this material, together with discarded lime from the factory, is beneficial in many cases, it should never be applied to the land if it has been infested with nematodes through the use of infested beets. That is, it should not be so used unless the nematodes contained in it have first been destroyed. This may be done by rendering the water in the settling pond decidedly alkaline through the addition of calcium hydrate. It has been found that an alkalinity of 0.03 per cent will destroy nematode larvæ in 24 hours; weaker solutions are uncertain. An alkalinity of 0.124 per cent kills mature females and their contained embryos in 11 days to the same extent that fresh milk of lime would kill them in 9 days. An exposure of 40 days to a solution of 0.031 per cent alkalinity kills both females and embryos with certainty (Schwartz, 1911).

Compost mixed with infested soil should never be applied to clean land, unless the nematodes have been destroyed by the addition of a considerable percentage of fresh lime to the mixture.

Trap Crops.—The method devised by the noted German agriculturist, Kühn (1881, 1882, 1886, 1891), has received greater attention and more has been hoped from its application than perhaps any other means of combating the beet nematode. This method is built upon the principle of catching the nematodes upon the roots of rapidly growing plants to which the worm is partial. Then the trap crop is destroyed by turning up its roots to the sun and wind, thus exposing at the same time such nematodes as may have attacked the roots.

The method is essentially as follows: Shortly after the beets have appeared above ground in spring, a trap crop of summer rape is sown between the rows of beets. The nematodes are attracted to the roots of the rape. At a period some days before the females are ready to deposit eggs, this crop is turned up, exposing roots to the sunshine and wind. This rapidly wilts the plants and kills the adhering nematodes. This uprooting of the rape should be done in dry, sunny weather. In moist or rainy weather the nematodes would survive and return to the soil. In such a contingency the trap crop would have to be gathered up as soon as it was uprooted, and carried away, to be at once thoroughly mixed with fresh lime to destroy the worms. It is necessary to sow as many as five or six trap crops during a single season. This method is both too precarious and too costly. Only a trained observer would be able to conduct it successfully. It has been generally abandoned.

Spiegler (1911) who has tried this method quite thoroughly, says of it:

> "Although I have not for some time been an adherent of this method, I must, for truth's sake, state that I have obtained marked results from it. * * * The increase per acre averaged 7.124 tons. On another tract of 175.441 acres, an average increase of 3.609 tons an acre was obtained. In spite of this I have abandoned the trap crop method, because I have found it like a two-edged sword, which cuts both ways. Through the slightest fault, lack of care, unsuitable weather, etc., the nematodes are actually increased in number, instead of being destroyed. Besides this, it is too costly, takes too much time, and requires the greatest attention and experience."

By fallowing and by sowing trap crops on five different plats which were completely infested by nematodes, Spiegler obtained the results shown in Table XIII.

Table XIII.—*Results of trials of the trap-crop method of beet nematode control, according to Spiegler.*

		Yield (tons per acre).	
Plat.	Area (acres).	Without trap crop.	With trap crop.
I.	2.471	4.461	13.561
II.	9.884	10.057	16.371
III.	22.239	9.368	21.323
IV.	24.71	7.940	13.606
V.	24.71	9.591	12.177

COMBATING THE PEST BY ROTATING NONSUSCEPTIBLE CROPS.

After long-continued research by the foremost investigators of Europe, the conclusion has been reluctantly reached that neither the application of chemicals, parasitic fungi, fertilizers, nor even the celebrated trap-crop method of Kühn are practicable. Each in turn has often been tried; all have been abandoned.

It was finally seen that advantage must be taken of the fact that the nematode will not attack certain crops, or infests them but slightly. The probability that biological varieties arise through gradual adaptation to particular crops, and the consequent inability to severely infest a constantly changing series of crops through the lack of time to become adapted, also led to the conclusion that a long-time rotation with nonsusceptible crops might be efficacious.

Thus it came about that a carefully planned system of rotation was worked out, in which susceptible crops appeared only once in six or seven years.

A description of the most efficacious method of handling this question, as suggested and practiced by Spiegler, follows:

Assuming that we have to do with land that has become more or less infested with the beet nematode, it is recommended that a series of sketch maps be made, representing each field. In connection with the maps each field should have its folio for recording conditions. The more or less infested spots should be clearly marked on the respective maps, and a record should be made on the proper folios of the manuring and cropping of the previous season. The weather conditions, soil character, as well as details of the composition of organic and artificial fertilizers, especially the calcium and potassium needs of each plat, should also be recorded. In this way we may discover that an irrational and irregular rotation has long been carried on, thereby, through our own fault, augmenting the number of both nematodes and other enemies. We are thus brought to realize that a better system must be employed.

The land might be divided into four classes for treatment: (*a*) That which has become completely infested; (*b*) fields in which infestation is partial or slight; (*c*) fields in which nematodes are found in sharply defined areas or spots; (*d*) those which are quite free from nematodes.

For class *a*, a 6 to 8-year rotation must be planned, including only such crops as will not be favorable to the nematode Among these are cereals (except oats), clover, various grasses, sainfoin, horse beans, common beans (*Phaseolus vulgaris*), poppy, caraway, maize, onion, and mixed forage crops (excluding oats).

Through repeated tilling the land will be rid of the remains of beet roots and the bacterial flora will be enabled to improve the soil conditions.

Repeated cultivation during the hot summer time causes part of the nematodes to penetrate into the deeper soil through the drying of the upper stratum. It would be of great advantage, where possible, to let infested land lie fallow for several years, provided all weeds were kept down.

By such a method, from fields where formerly Spiegler could obtain only 5.576 tons per acre of beets that were almost useless for the factory, he thus obtained, in 1906, 16.951 tons per acre, and he, therefore, strongly recommends the method.

Class *b* must also be treated very carefully. No beets should be grown on slightly infested land for four or five years. It is recommended by Spiegler that the rotation be so arranged as to include clover, horse beans, potatoes or mixed forage crops between cereals.

Such a field, in 1901, yielded 11.152 tons to the acre. It was then treated as follows: 1901, beets; 1902, barley; 1903, beans; 1904, wheat (without manure); 1905, mixed forage, and in 1906 he obtained a yield of 20.074 tons of beets per acre.

Thus it will be seen how responsive a field may be to such consideration, and how ample is the reward, yet how simple is this method of decimating the nematodes. Such a system also, to a large degree, prevents the establishment of other pests and diseases and greatly improves the land.

The sudden appearance of nematodes may sometimes be noted where none had been seen before, doubtless being local infestation through the transportation of the pest by one of the many possible means. Such cases come under class *c*. Such lands should receive the greatest attention during June and early July (the time will vary greatly in the different beet districts of the United States, but it is the time when the symptoms of nematode infestation become unmistakable in the beets), especially in dry, hot middays, to detect every infested spot. Should one or more such areas be discovered through drooping leaves of a sickly, dark-green color, one may be able to discover with the naked eye the ofttimes numerous adult females on the rootlets. Having made certain of this, all the beets in the infested area should at once be pulled up, care being taken to get all rootlets from the ground and, with their adhering soil, consign them to destruction. The infested spot must be isolated by digging around it a narrow trench about 12 inches deep, and in this trench fresh lime must be scattered. After having rid the infested spot of rootlets, it is thickly spread with fresh lime, which should be thoroughly mixed with the soil. This mixing must frequently be repeated during the hot weather, as well to hasten the drying out of the nematodes as to destroy weeds. Further (or as a substitute) it would be well to employ the hitherto-described Hollrung method of applying carbon disulphid, using it liberally. Thus the spot may be completely isolated and the further spread of the parasite checked.

Class *d:* In fields hitherto free from the pest it is necessary to exercise the greatest watchfulness that no nematodes be carried to it from already infested fields, since it would avail little to fight the parasite through costly and laborious methods, if we again spread it through thoughtlessness.

The accumulated beet soil conveyed with beets to the factory, and the mud and slime which are deposited in the settling pond should never be carried to fields. This material should be disposed of by composting it with liquid manure and quicklime. After allowing it to lie several years, with frequent stirring, it would be fine for applying to isolated, wet pastures.

Above all, a carefully planned, long-time rotation system should be carried out. This practice should be general, whether the land be infested or not.

CROPS AVAILABLE FOR ROTATION ON INFESTED LAND.

Since the beet zone of the United States embraces many States and a great diversity of climatic conditions, it will be necessary to make some kind of grouping or classification in order intelligently to work out suitable rotation series for the whole zone.

The following classification is suggested:

Group 1. California and Arizona.

Group 2. Oregon and Washington.

Group 3. Utah, Montana, Nevada, Colorado, Kansas, South Dakota.

Group 4. Nebraska, Wisconsin, Indiana, Michigan, Ohio, New York, and West Virginia.

NONSUSCEPTIBLE CROPS.[1]

Group 1: Cowpeas, soy beans, sweet clover, wheat, barley, rye, the millets, tomatoes, asparagus, lettuce, cantaloupes, strawberries.

Group 2. Cowpeas, soy beans, sweet clover, wheat, barley, rye, millets, truck crops such as lettuce, asparagus, etc. (excluding celery).

Group 3. In addition to those under class 2 add potatoes, cantaloupes, and cucumbers.

Group 4. Clover, cowpeas, sweet clover, soy beans, wheat, barley, rye, the millets, potatoes, tobacco, flax, peppermint, cucumbers, strawberries, melons, lettuce, asparagus, some other truck crops, and the grasses, with the exception of tall oat grass (*Arrhenatherum*).

It is quite probable that it would be practicable to include some of the crops upon which the nematode has been reported should a six or seven-year rotation be carried out. The frequent change of crops would give the nematode little chance to become adapted to any one kind of crop.

TREATMENT OF BEET SEED TO DESTROY THE NEMATODE.

It has been demonstrated that some species of eelworm can withstand drying for long periods, e. g., *Tylenchus dipsaci.* It is probable that the brown-cyst stage of the sugar beet nematode can survive on commercial beet seed and thus be introduced into this country. Should it be proved that either *Tylenchus dipsaci, Heterodera schachtii,* or other destructive species are brought in on beet seed, methods of ridding the seeds of such pests should be available.

It has been shown that the free-living forms of *Heterodera schachtii* are very sensitive to desiccation, and for that reason would be unable to survive on commercial beet seed imported into this country. Small lumps of soil conveyed among beet seeds might retain sufficient moisture to preserve even the larvæ of the beet nematode. However, since the significant work of Fuchs has recently demonstrated that the

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[1] In Germany the potato is generally included in the rotation series, since this crop is not subject to severe infestations.

The same is true of wheat, barley, and rye. Corn and lima beans should be added to groups 1 and 4 as being only slightly susceptible preservation or resistant form of this parasite, the so-called "brown cyst," can survive great extremes of temperature and of drought and still retain its contents, the eggs, in a viable condition, it would appear that practically all doubt is removed, so far as it can be without actual demonstration, that in such a form the beet nematode has been, and still is being, introduced into this country. This would seem the more certain from the fact that the pest has manifested itself only in the two oldest beet districts of the United States. There is no certainty that any other vehicle for the importation of the parasite has been available, although, as previously suggested, nursery stock and other agricultural products may have been a means. The rough surface of beet seedballs might easily hold numerous brown cysts. But it is neither probable nor necessary that any considerable number of the cysts should be present in any sack of beet seed because in the long run, where beets are repeatedly planted in the same fields for a long succession of years, the small foci of infestation resulting from but a few brown cysts would be sufficient to cause the sporadic establishment of the nematode in those districts; then it is but a question of time for their increase to become great enough to attract attention.

By oft-repeated tests Fuchs has clearly demonstrated that even the brown cyst is unable to protect its contents against a temperature of 63° C. At this temperature, applied without moisture, all eggs and larvæ contained within the brown cyst are killed.

This fact is believed to be the key to the solution of the problem of at least preventing the further introduction of this formidable foe of sugar beets with the seed. It appeared probable that beet seed might withstand a dry temperature far exceeding that mentioned as necessary for the destruction of the contents of the brown cyst, without injuring the germinability of the seed.

To this end some samples of sugar beet seed were selected for the test. For the purposes of the experiment a water-jacketed copper chamber was employed. A close-fitting cover, through which the bulb of a thermometer was passed, was provided for the chamber. The water was heated by a gas jet controlled by a thermoregulator. When the temperature within the chamber had reached the desired point, the cover was rapidly removed and a small basket of wire mesh, in which a quantity of beet seed had been spread, was quickly set upon small corks placed in the bottom of the chamber. The basket was placed on corks in order to prevent direct contact with the walls of the chamber and to allow a free passage of air around the seedballs.

On placing the basket of seed in the chamber, the temperature of the latter immediately fell several degrees, partly owing to the momentary removal of the cover, and in part on account of the vaporization of moisture in the seedballs, and the absorption of a portion of the heat by the seedballs themselves. After the desired temperature had been resumed, the seed was retained in the chamber for the indicated period.

The following notes were made in the course of this experiment:

Sample No. 1.—Control, untreated seed; Utah stock of 1910.

Sample No. 2.—One minute at 63° C. Put seed in chamber at 63° C. at 1 p. m. At once the temperature fell to 59° C. and had again risen to 63° C. at 1:09, where it was held for 1 minute, the seed then being immediately taken out.

Sample No. 3.—Five minutes at 63° C. Put seed in chamber at 63° C. at 1:11 p. m. The temperature fell to 59° C. at once, rising to 63° C. at 1:21½ and was held there until 1:26½.

Sample No. 4.—Ten minutes at 63° C. Put seed in chamber at 63° C. at 1:27½ p. m. The temperature at once fell to 59.5° C. and rose to 63° C. at 1:34 and was held there until 1:44 p. m.

Sample No. 5.—One minute at 70° C. Put seed in chamber at 70° C. at 1:50 p. m. The temperature fell to 64° C. at 1:52; rose to 70° C. at 2:02 and was held there for one minute.

Sample No. 6.—Five minutes at 70° C. to 71° C. Put seed in chamber at 70° C. at 2:04 p. m.; fell at once to 65° C.; rose to 70° C. at 2:14; rose to 71° C. at 2:17; held there until 2:19.

Sample No. 7.—Ten minutes at 70° C. to 71° C. Put seed in chamber at 70° C. at 2:21 p. m.; at once the temperature fell to 67° C. and rose to 70° C. at 2:27; rose to 71° C. at 2:29 and remained there until 2:37 p. m.

The treated samples of seed were then turned over to the seed laboratory of the Department of Agriculture for germination under standard conditions. From the results of the germination of this first series of samples, it was found that the seed fell much below the Magdeburg standard of germination, but since the treated seed was compared with untreated seed of the same lot that fact is not material. The results obtained are as shown in Table XIV.

Table XIV.—*Germination test of treated and untreated beet seed of Utah Stock of* 1910.

Sample No.	Treatment.	Duration of test days.	Germination of seed-balls, percent.	Number of sprouts per 100 seed-balls.
1.	Control (untreated)	13	53	88
2.	1 minute at 63° C.	13	46	79
3.	5 minutes at 63° C.	13	41	68
4.	10 minutes at 63° C.	13	58	85
5.	1 minute at 70° C.	13	70	126
6.	5 minutes at 70° to 71° C.	13	61	102
7.	10 minutes at 70° to 71° C.	13	48	77

A second and fresher lot of seed was then selected and subjected to similar treatment. The following notes were taken:

Sample No. 1.—Control, untreated seed; Utah stock of 1912.

Sample No. 2.—One minute at 63° C. Put seed in chamber at 63° C. at 10:02 a. m. The temperature fell to 61° C. at 10:03; rose to 63° C. at 10:06 and was held there for one minute.

Sample No. 3.—Five minutes at 63° C. to 65° C. Put seed in chamber at 63° C. at 10:13 a. m. The temperature fell to 62° C. at 10:14; rose to 63° C. at 10:15 and was held for five minutes between 63° and 65° C.

Sample No. 4.—Ten minutes at 63° C. to 65° C. Put seed in chamber at 63° C. at 10:30 a. m. The temperature fell to 61° C. at 10:31; rose to 63° C. at 10:33 and was held between 63° and 65° C. for 10 minutes.

Sample No. 5.—One minute at 70° C. Put seed in chamber at 70° C. at 11:00 a. m. The temperature fell to 66° C. at 11:01; rose to 70° C. at 11:05 and was held there for one minute.

Sample No. 6.—Five minutes at 70° to 73° C. Put seed in chamber at 70° C. at 11:11 a. m. The temperature fell to 69° at 11:12; rose to 70° at 11:13; held between 70° and 73° C. for 5 minutes.

Sample No. 7.—Ten minutes at 70° to 75° C. Put seed in chamber at 70° C. at 11:28; temperature fell to 69° at 11:29; rose to 70° at 11:31; held between 70° and 75° C. for 10 minutes.

Sample No. 8.—Fifteen minutes at 75° C. Put seed in chamber at 75° C. at 2:19 p. m. The temperature fell to 69° C. at 2:22; rose to 71° at 2:30, to 73° at 2:35; held for 15 minutes between 73° and 75° C.

This series was also sent to the Seed Laboratory of the Department of Agriculture for a standard germination test. The results at the end of 5 and 10 days are shown in Table XV.

After allowing for a normal range of variability, it seems obvious from the results of these tests that the exposure of the seed in the manner described has not diminished their germinability, with the possible exception of the last number in each series. Even in those cases the diminution is only such as might occur between different random samples from the same lot of seed. In the first series it is quite evident that the sample of seed was a poor one, but the germinability of the second series was excellent.

In both series a stimulation of germinability is apparent, the percentage of several members of each series exceeding what might be considered a normal variation. This would seem to confirm the work of Hegyi (1911), who has recently shown that a reduction of the water content of beet seeds increases their germinability, makes the seedlings more vigorous and more resistant to damping-off fungi. He found this to be true whether the water content were reduced by artificial means (he dried them at a temperature of 55° C.) or by natural means, such as the comparative drouth or low relative humidity of one district as compared with another.

Since Fuchs has demonstrated that all the contents of the preservation form of the beet nematode are killed upon exposure for even a brief time to a temperature of 63° C., it is obvious that the above described treatment of beet seed will at the same time leave the seed uninjured and destroy all forms of the parasite. Not only so, but there is an apparent gain in the germinability of the seed through the resultant diminution of the water content.

Since a temperature of 63° C. applied for so short a time as one minute is sufficient for the destruction of the brown cysts, and since beet seed is not injured by an exposure of 10 minutes to a dry heat of 75° C., it appears safe to recommend a treatment of five to ten minutes at a temperature ranging between 65° and 70° C., with the certainty that it will destroy all forms of the beet nematode that may be upon or among beet seeds.

It should be a comparatively easy matter, and certainly an inexpensive one, to apply this treatment on a large scale to commercial beet seed. A large cylinder of brass wire mesh, fine enough to retain beet seed, inclined slightly from the horizontal, with a spiral flange running from one end to the other within the cylinder, might be so constructed as to revolve at such a rate as to carry the incoming seed entirely through the cylinder in a given time, the time necessary to expose the seed to the required temperature being ascertained by experiment. The cylinder should revolve within a closed chamber through which a blast of hot air is driven. It will be seen from the notes on the experiment hitherto described that immediately after placing the seed within the hot chamber the temperature fell; it then remained stationary for some time, after which it slowly rose. This was due to the evaporation of the moisture contained in the seed, as well as to the actual absorption of heat by the seed. In such an apparatus as is suggested, this fact would have to be recognized, therefore the blast of hot air would probably require to be some degrees higher than that to which it is desired to raise the temperature of the seed itself.

In view of the dangerous character of the sugar-beet nematode, and of the fact that there can be little doubt of its admittance to this country on imported beet seed, the advisability of immediate steps to render it obligatory for all imported beet seed, either at or before entry to the United States, to be subjected to such treatment, should be taken under consideration.

Further investigations are planned to demonstrate beyond doubt whether or not the beet nematode, in any of its forms, is carried on European beet seed, and thus introduced into this country.

However, since it has been shown that such a treatment is actually beneficial to the seed, that it will destroy the nematode, if it be present, and that the method is entirely practicable and inexpensive, there is every reason to urge that its application be enforced as soon as possible.

BREEDING STRAINS OF BEETS RESISTANT TO THE NEMATODE.

It is quite possible that the sugar beet itself, as well as other crop plants susceptible to beet-nematode attack, may be made to defend themselves against this enemy.

It has been seen that chicory, for example, is not only nonsusceptible to attack, but is actually so repugnant to beet nematodes as to repel, even to kill them. This is probably due to the presence in the cortex of chicory roots of some property distasteful or toxic to these worms. Wilfarth (1900) suggested the possibility of creating, through breeding and selection, a strain of beets resistant, or shall we say distasteful, to nematodes by developing an acrid or bitter principle in the epidermis of the roots.

The way has already been blazed for such work. Orton (1910-1911) and Gilbert (1912) have developed a variety of cowpea practically resistant to root-knot and wilt *(Neocosmospora vasinfecta)*, other kinds being very susceptible. Bessey (1911) found that of the watermelon-citron hybrids bred by Orton for wilt resistance, one strain showed the presence of root-knot to the extent of only 1.2 per cent, as against 28 and 51.9 per cent, respectively, in two other strains. It has also been shown by Bouquet de la Grye (1899) that *Coffea liberica* is less susceptible than *C. arabica* to the attacks of the root-knot nematode. On that account he recommends grafting *C. arabica* upon *C. liberica.* Some figs, such as the Celeste and Poulette, are reported to be not so susceptible to nematode injury as other kinds. Most of the Old World species of grapes, although differing in degree among themselves, seem to be exceedingly open to injury by the root-knot nematode. On the other hand, some of the phylloxera-resistant hybrids and pure American vines are practicaly immune to both phylloxera and root-knot; yet other American varieties are subject to nematode attack. This is confirmed by the observations of Lavergne.

As applied to the sugar beet, this is a problem that might well be taken up in the United States by the U. S. Department of Agriculture, State experiment stations in the beet zone, and by the few agencies as yet interested in raising beet seed. It also deserves thorough study by the great European sugar-beet seed firms, upon whom at present American beet growers are almost entirely dependent. So far as other susceptible crops are concerned, simple selection is recommended for every farmer who raises his own seed. In fields infested with beet nematodes it will undoubtedly be noted that some plants appear to be, to a greater or less extent, immune; this is true even of sugar beets, which are notably susceptible. Such plants might be selected and preserved for seed purposes. Crossing might later be effected among a number of such more or less immune plants, until eventually individual plants might be found practically immune, and capable of transmitting that quality. These selections should always be made in badly infested fields, otherwise there would be no assurance that such plants had not simply escaped attack on account of the irregular distribution of the parasite, rather than actually showing some degree of immunity. Methods of selection and breeding have been described in detail in other publications.

TABLE XV.—*Germination test of treated and untreated beet seed of Utah stock of* 1912.

Sample No.	Treatment.	Seedballs —germinated in— 5 days. Per cent.	10 days. Per cent.	Number of sprouts per 100 —seedballs in— 5 days.	10 days.
1	Control (untreated).	92	94	209	212
2	1 minute at 63° C.	94	94	207	208
3	5 minutes at 63° to 65° C.	93	93	202	203
4	10 minutes at 63° to 65° C.	99	99	242	242
5	1 minute at 70° C.	91	92	191	194
6	5 minutes at 70° to 73° C.	94	95	216	217
7	10 minutes at 70° to 75° C.	90	90	202	202
8	15 minutes at 75° C.	89	89	192	192

CONCLUSION.

It is urged that the agriculturist and field corps of every beet-sugar factory in the United States, especially those in the districts already known to be infested with the beet nematode, familiarize themselves with the facts essential to the recognition and practical methods of combating this pest, in order that they may be able to assist the beet growers in its detection and extermination.

In the meantime, further investigations are necessary to determine:

(a) With certainty how the sugar beet nematode is brought into this country.

(b) What plants in this country are really resistant to it.

(c) Whether, through selection and breeding, resistant strains of beets may be produced.

(d) Where, besides the localities already mentioned, it has been distributed.

(e) What measures are necessary to prevent its further introduction and wider distribution in the United States.

SUMMARY.

(1) A pathological condition of sugar beets began to appear in the fields of many European beet districts some years after the cultivation of that crop had become general; a condition that, ere long was attributed to a depletion of certain mineral plant foods, especially potassium salts, in the soil. Since this was most frequently observed where beets had been grown many years in succession, it was concluded that the soil was no longer able to sustain the growth of sugar beets, hence these fields were said to be *"Rübenmüdig"* (beet tired, or beet weary), the condition of the soil then being designated *"Rübenmüdigkeit,"* or beet weariness. This phenomenon rapidly became so widespread and caused so great a reduction in the yield and sugar content of affected beets as seriously to threaten the whole industry.

In such fields the beets manifest the following characteristic symptoms: The outer leaves wilt and turn yellow about the end of July or early in August, but in bad cases as early as June; the inner leaves fail to attain normal size; in severe cases the crown becomes black and rots, on account of the inability of the affected beet to resist the attacks of fungi, and the flesh turns brown. The heart leaves, if they survive, assume a very dark green hue, which is quite conspicuous. In severe cases the beets may die before harvest.

Thorough studies were begun to determine the true cause of these symptoms, and it was soon shown that innumerable tiny eel worms were always present in the soil and among the rootlets of beets in these "beet-weary" fields. This worm was first described by Schacht, in 1859, and more fully by Schmidt, during the same year; the latter writer named the parasite *Heterodera schachtii*. It was soon afterward demonstrated, notably through the labors of Kühn and Liebscher, that this parasite is the real culprit.

Adult females of the causal parasite may be found attached by their head parts to the fine rootlets of infested beets about the time the latter begin to show signs of distress. These look like tiny, dull, milky-white cysts or beads clinging to the small rootlets. Later they leave the plants.

(2) The present distribution of the pest is very extensive, including Germany, Austria-Hungary, western Russia, Holland, Belgium, France, Denmark, Sweden and the Azores. It has also been reported on hops in England. In the United States it has become established in two of the oldest beet districts, viz., in California and Utah.

(3) It is polyphagous and has been reported, according to Marcinowski and Vañha and Stoklasa on 60 species of host plants. Practically all of these plants are found in the beet zone of the United States either as introduced wild plants or in cultivation. Probably many other plants native to this country would be susceptible to attack.

(4) The beet nematode, as well as the root-knot nematode, may be of European origin, but it is more probably from tropical or semitropical countries and may have been conveyed to Europe many years ago with exotic plants.

(5) In the beet fields of European countries, its ravages began to be noted early in the seventh decade of the nineteenth century. It became very generally distributed, and still is one of the serious menaces to the beet industry of Europe.

(6) According to Strubell, the life cycle of the female nematode occupies from four to five weeks, being almost identical with that of the root-knot nematode. As many as six or seven generations may be produced in one season. The worm attacks the plants during its larval stage. Only the head parts of the larvæ penetrate thin rootlets, but sometimes the whole body becomes embedded in the tissues of thicker roots. After settling upon the rootlets, the larvæ are for a time quiescent and there undergo metamorphosis. The male finally resumes the eel-like form of the larvæ, breaks free from the rootlet, seeks a female, and, after conjugation, dies.

After metamorphosis, the female assumes a distinct lemon shape and remains with her head parts inserted in the rootlet until her 350 to 400 eggs are matured. Some of the eggs may be hatched within the body of the living female, but she generally dies before all the young escape from her body. At the approach of cool weather of late autumn, many of the pregnant females undergo a further change—their bodies become brown, the integument being greatly thickened and toughened. The female herself dies and her modified body becomes simply a sac filled with eggs. This sac constitutes a resting or preservation stage and in it the eggs may be preserved for several years in a viable condition.

(7) The beet nematode is apparently capable of adaptation to particular host plants, thereby developing biological varieties in the course of several generations. This is sometimes accompanied by modifications in size and proportions.

(8) For its rapid multiplication the following conditions are essential: (a) Since it is especially sensitive to cold, at least in the egg and larval stages, a fair amount of heat is necessary for its active development; temperatures ranging from 15° to 20° C. are favorable; above or below this their development is inhibited or arrested. They are as surely killed by a temperature of 35° C., as by frost. Yet the brown-cyst form of the adult female is capable of surviving the rigors of winter on the surface of the ground; therefore, to destroy the contents of the brown cyst, a temperature of not less than 63°C. is required. (b) Since it is larger and has a more robust spear than the root-knot nematode, the activities of this parasite are not limited to light soils, but it is capable of thriving in any good beet soil. It is doubtless more active in the lighter soils. (c) The free-living forms of the sugar beet nematode, unlike *Tylenchus dipsaci* and some other eelworms, can not withstand a lack of moisture; nor, on the other hand, can they endure a thoroughly saturated soil, but they thrive best in a well-aerated soil with suf-

ficient moisture for plant growth. The drying out of the soil will cause their death. (d) The brown-cyst form of the nematode, however, can withstand considerable drought.

(9) Food supply: Strubell observed that the larvæ are able to develop almost to the sexually mature stage in soil free from plants. Chatin also proved experimentally that they can live for a whole generation in plant-free soil and propagate themselves. They are able to subsist on the roots of numerous plants, especially those of some of the common weeds now abounding in the United States. More recently Fuchs has found brown cysts to endure five years in the soil and their contents to remain viable at the end of that time.

(10) These worms are spread in many ways: (a) By their own activities the larvæ are capable of moving through the soil about 75 to 100 feet, through the combined travels of seven generations in one season, according to the estimate of Fuchs. This is probably over the mark; 50 to 75 feet would be more reasonable. Their more rapid and extensive distribution is to be found in other ways: as, (b) From field to field in soil clinging to implements, to hoofs of animals, to the shoes of laborers and others who may traverse the fields, to wagon wheels, and by means of the soil shaken from infested beets into wagons. (c) Frequently they are spread by heavy rains, and may be carried long distances by irrigation water. (d) Although eggs and larvæ may be transported by heavy winds with sandy soil, it is probable that this would dry them sufficiently to destroy them, yet the cysts may survive such transportation. (e) It is undoubtedly possible to distribute them in soil clinging to the roots of nursery stock, potted plants, bulbs, rooted cuttings, potatoes, and possibly in some kinds of packing used for such stock. (f) It is not certain that any of the free-living forms of this nematode are brought into this country in a live condition on beet seed, although some of the more resistant types of eelworms may be thus introduced, but it is quite probable that the cyst stage is conveyed in a viable condition among beet seed. (g) This pest may be transferred to uninfested fields with manure that has stood in an infested field. (h) Mud and slime from the factory settling pond, as well as beet waste from the factory, would be a prolific source of infestation if spread on the land. These materials should never be so used until they have been composted with liquid manure and quicklime for several years, with frequent admixture. (i) The pest may be distributed, or at least held over, on the roots of weeds allowed to grow on the roadside, on the margins of fields and along irrigation ditches, and in the fields after crops have been harvested.

(11) The effect on the infested beets is very serious. Great quantities of the plant juices are abstracted. The conducting vessels of rootlets and the body of the beet become plugged with complexes of giant cells, thus seriously interfering with the plant activities; hence, the wilting and death of the leaves. Many rootlets are killed and new ones are constantly stimulated into growth, thus bringing about the condition known as "hairy-root," etc. Secondary infections take place through the entrance of fungi and bacteria, thus causing the beet to rot.

(12) Innumerable methods of combating the pest have been studied and tried. Chemicals, such as carbon disulphid, gas water, gas lime, etc., have been applied directly to the soil, but such methods are too costly, except for small areas. Kühn developed an elaborate trap-crop system, but this has been abandoned as too laborious, precarious, and costly. For a time, fertilizers appeared to have favorable effects, but it was found that they did not injure the nematodes.

(13) Finally, rotation systems were carefully worked out. These were designed to run six to seven years, and to include only one susceptible crop, such as beets, once in that period. This, in general practice, is the only method found available. Crops appropriate to the various beet districts should be selected from those known to be nonsusceptible to attack. Beets should be included but once in a 6-year or 7-year series. Later writers advise a rotation extending over eight years, in order to insure the destruction of the brown cyst.

(14) Careful observations should be made by farmers to detect the first symptoms of nematode infestation. Infested land should be indicated on sketch maps and their thorough treatment be undertaken before the pest gains greater headway.

(15) It has been found practicable to expose beet seed to a dry temperature of 65° to 70° C. for 5 to 10 minutes, not only without injury to the seed, but with a stimulation of its germinability. Since a temperature of 65° C. is sufficient to kill the contents of the very resistant brown cyst, when applied even for so short a time as one minute, and since all the free-living forms are killed at a temperature of 35° C., we have here a simple, inexpensive and practical means of destroying all such parasites that may be carried on or among beet seeds. It is recommended that such treatment of all imported beet seed be made general.

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Description of Plates

PLATE IV.

Fig. 1.—The first larval stage of *Heterodera schachtii.* X 330.

Fig. 2.—The spear of the larva of *H. schachtii.* X 1450.

Fig. 3.—The flask stage of the larva of *H. schachtii.* X 200.

Fig. 4.—The spear of the adult beet nematode. X 1450.

Fig. 5.—Swellings on a beet rootlet caused by larvæ of the sugar beet nematode. X 15.

Fig. 6.—The male nematode developing within the larval skin. X 200.

Fig. 7.—The adult male of *H. schachtii.* X 200.

Fig. 8.—The adult female of *H. schachtii*, with adhering portions of the larval skin. X 30.

Fig. 9.—Female of *H. schachtii* attached by her head parts to the rootlet of a beet. X 15. (After Strubell.)

Explanation of letters: k = the lips; m = the mouth; st = the spear; ms = muscles controlling the movement of the spear; dr = glands; oe to oes = œsophagus; ex = excretory duct (Dr. N. A. Cobb has proposed the name "renette" for the whole organ of which the part indicated and previously known as the excretory duct is only an outlet. The word is a direct diminutive of *ren, renis*, a kidney L.); d = intestines; gt. = embryonic sexual organs; a = anus; bulb = muscular bulb of the œsophagus; schl = nerve ring; h = testicle; sm = muscles attached to spicula; sp = spicula.

PLATE V.

Fig. 1.—*Heterodera schachtii*, male. X 86.
Fig. 2.—*H. schachtii*, larva. X 76.
Fig. 3.—*H. radicicola*, larva. X 115.
Fig. 4.—*H. schachtii*, male, in last larval skin. X 16.
Fig. 5.—*H. radicicola*, male, in last larval skin. X 16.
Fig. 6.—*H. schachtii*, female. X 39.
Fig. 7.—*H. radicicola*, female. X 78.
(Figs. 1, 2, 3, 5 and 7 after Marcinowski; Fig. 4 after Strubell.)

Fig. 8.—Stages of *H. schachtii*: *a*, egg; *b*, recently formed "brown cyst"; *c*, *older* state of brown cyst, showing gall-like mass (*d*) extruded from vulva. X 40. (Original drawing.)

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